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Debris Analysis Workstation Version 0.1 User's Guide

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The Debris Analysis Workstation (DAW) Version 0.1 is an ensemble of spacecraft breakup, trajectory propagation, and data visualization models cohesively integrated into a single user-friendly analysis environment designed for operation on a SUN workstation. DAW was developed by the Aerospace Corporation for the Air Force Phillips Laboratory Space Debris Research Program. Equipped with a graphical user interface and easy-to-use data presentation graphics, analysts can use DAW to model a variety of scenarios involving the fragmentation of a target object resulting from either a self-explosion or a collision with another object. The user initiates a desired breakup study by inputting such information as the type of breakup event, the position and velocities of object(s) involved in the event, and the object(s) material and structural characteristics. The study can then be run in DAW 0.1 to obtain a variety of information on the breakup. This information can include initial distributions of fragments generated in the event, the subsequent evolution of the fragment cloud(s), and the reentry footprint of individual fragments at some specified altitude(s) or those impacting the ground.

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Chapter 1.0 DEBRIS ANALYSIS WORKSTATION OVERVIEW

1.1 Overview

The Debris Analysis Workstation (DAW) Version 0.1 is an ensemble of spacecraft breakup, trajectory propagation, and data visualization models cohesively integrated into a single user-friendly analysis environment designed for operation on a SUN workstation. DAW was developed by the Aerospace Corporation for the Air Force Phillips Laboratory Space Debris Research Program. Equipped with a graphical user interface and easy-to-use data presentation graphics, analysts can use DAW to model a variety of scenarios involving the fragmentation of a target object resulting from either a self-explosion or a collision with another object. The user initiates a desired breakup study by inputting such information as the type of breakup event, the position and velocities of object(s) involved in the event, and the object(s) material and structural characteristics. The study can then be run in DAW 0.1 to obtain a variety of information on the breakup. This information can include initial distributions of fragments generated in the event, the subsequent evolution of the fragment cloud(s), and the reentry footprint of individual fragments at some specified altitude(s) or those impacting the ground.

Figure 1-1 shows the functional organization of the current DAW system. DAW Version 0.1 incorporates the IMPACT 4.0 (Refs. 1, 2) breakup model and FOOTPRINT (Ref. 1) fragment dispersion pattern models. These component models have been developed over the last ten years by the Space Hazards Section of the Aerospace Corporation Systems Engineering Division for performing various space debris related studies. For the DAW 0.1 system, enhancements have been made to these component models to make them suitable for missile intercept and range-safety analysis at the White Sands Missile Range (WSMR), New Mexico, in support of the U.S. Army Theater High Altitude Area Defense (THAAD) Project. Enhancements include the following:

- Addition of a new drag-inclusive trajectory propagator to FOOTPRINT that accounts for both atmospheric (ballistic) drag and wind effects near the earth's surface. Atmospheric density and wind models are based on local WSMR specific data.
- Incorporation of a new on-screen map plotter that displays WSMR map boundaries and other local information
- Addition of a collision dispersion model to simulate the average and maximum ellipsoidal footprint boundaries of fragments produced in a collision breakup event for a given confidence level
- Incorporation of routines to accept and transform position and velocity data among five different coordinate systems
- Incorporation of breakup model enhancements in the IMPACT version 4.0 model

The component models may be run as separate user-selected modules within DAW 0.1 (although there are some requirements to the sequence they may be run). The invocation of each model, the input of parameters and information required for each model, and the subsequent reporting and plotting of the data generated by each model are handled interactively by the DAW study manager through a graphical user interface. Utilizing the X-Window Motif graphics protocol, this interface provides a variety of pop-up windows and pull-down menus to facilitate program operation. A data graphics presentation tool called

ACE/gr (Ref. 4), developed at the Oregon Graduate Institute of Science and Technology, provides on-screen and hardcopy support for plotting the DAW model results and has its own convenient point-and-click interface for defining plot styles, scales, and other plot operations.

The initial breakup fragment mass and velocity distributions are modeled using the IMPACT 4.0 model. The IMPACT model was originally developed to simulate the collision breakup characteristics of the U.S. Air Force P-78 antisatellite (ASAT) test in 1985 and the Delta-180 on-orbit hypervelocity collision test conducted by the Strategic Defense Initiative Organization (SDIO) in 1986. Later, the model was expanded to include an explosion model to simulate possible explosion breakup events which have mass and velocity distributions that differ from those typically found in hypervelocity collisions. IMPACT 4.0 is based upon a database of hypervelocity data and efforts have been initiated to incorporate THAAD-supported hypervelocity sled test data into later versions of IMPACT 4.0. Whether a collision or explosion breakup event is modeled, a wide variety of data is computed and can be graphically displayed with the ACE/gr tool. These data include the energy distribution associated with the overall breakup event, and characteristic number of fragments, total mass, ballistic coefficient, and average spread velocity associated with ensembles of fragments *binned* by mass or size (mean fragment diameter, kinetic energy, and ballistic coefficient). If desired, the IMPACT 4.0 model can also statistically assign values of the orbit, mass, dimensions, density, net earth centered inertial (ECI) velocity vector, rotation rate, and ECI rotation axis for a selected set of individual fragments. IMPACT output files containing these data can then be used by a variety of other space debris related models including FOOTPRINT, LIFETIME, DEBRIS, and DEBRA. The latter three models, which perform a variety of orbital debris related analyses, are envisioned to be incorporated into later versions of DAW.

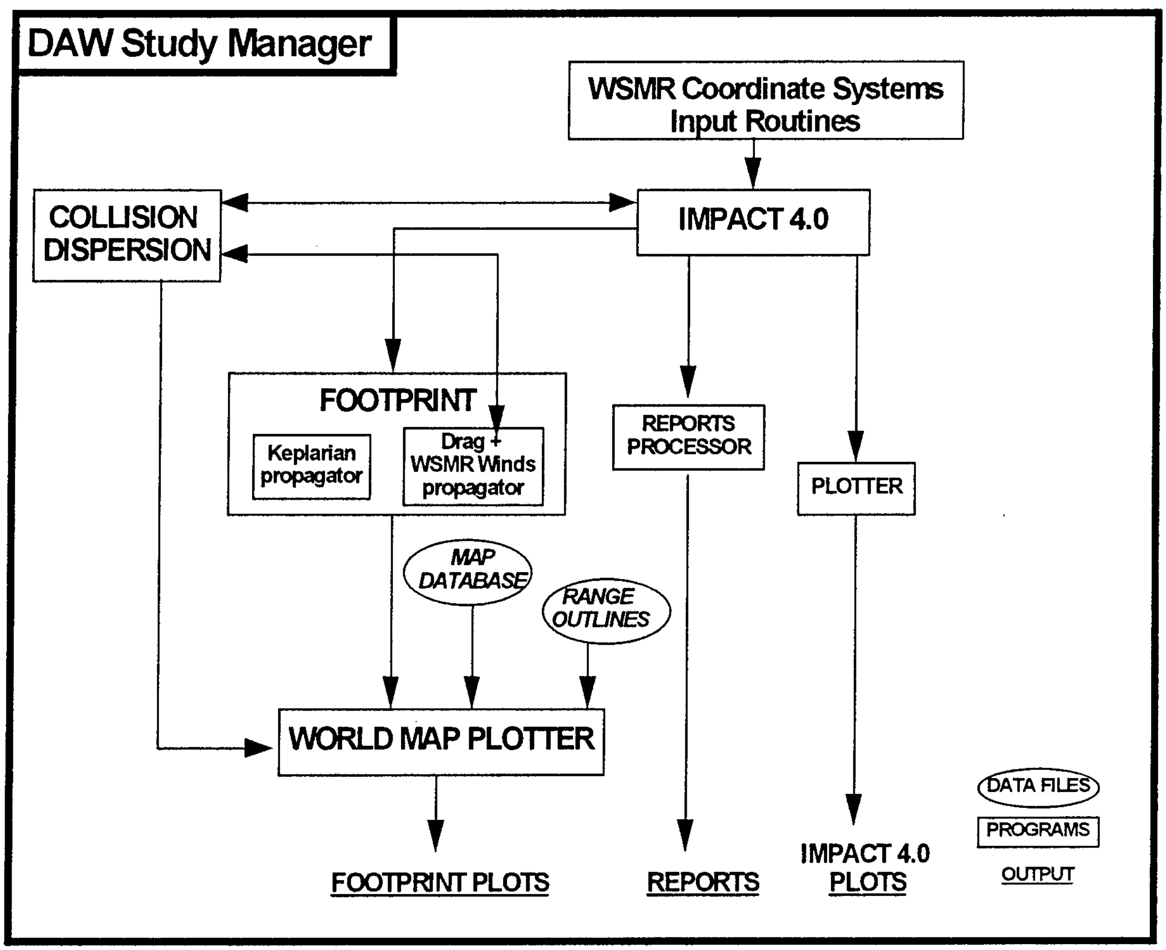


Figure 1-1. Functional Block Diagram of the Overall DAW 0.1 Design.

The FOOTPRINT model propagates individual fragment trajectories from a suborbital or orbital breakup to determine the spatial pattern of debris at a given altitude that reenter within one orbital revolution, including those that impact the ground (e.g. the impact footprint). The spatial fragment pattern can then be graphically displayed upon a map plot. Individual debris fragment ECI velocity vectors produced by a previous run of the IMPACT fragmentation model are propagated using one of three user-selected orbital propagators. A Keplerian propagator determines the altitude at each time step along the Keplerian orbit determined by the net velocity vector at breakup. If the user-specified minimum threshold altitude is reached the object's position is recorded and plotted. The main advantage of this model is computational speed, especially if a large number of fragments are considered. The user may also select a drag-inclusive propagator which models the orbital decay caused by atmospheric drag and winds. For WSMR range-safety hazard analysis purposes, the drag-inclusive model contained in DAW 0.1 has been updated to include the effects of atmospheric drag and winds (based on WSMR statistics) on debris trajectories and their resulting spatial footprints.

Chapter 2.0 GUIDE TO DAW USER INTERFACE

This chapter describes how to operate the DAW 0.1 graphical user interface and provides a summary guide to the input windows and menus found in DAW. A description of each menu item and window entry is given to guide the user in selecting the proper values. The graphical user interface utilizes the X-Window Motif protocol under the UNIX operating system. Using a mouse, the user may point and click to select most of the window and menu options found in DAW. A summary of pertinent X-Window operations and basic terminology necessary to navigate the DAW system is given in the Section 2.1.

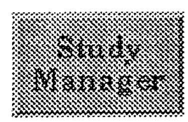
Beginning with Section 2.2, the various individual interface windows and their contents are described. In each section, a brief explanation is given for each of the available window commands and input options. Options are generally identified by their text labels displayed in the window (e.g. **Type:**). In certain cases where a group of *related* options are not explicitly identified under a *general* label, they classified in an option category. These categories are listed as underlined entries (e.g. <u>Vehicle Type</u>). The individual options within the category then are listed in each section followed by their explanations.

2.1 Window Basics

(*Note:* unless explicitly stated otherwise, the term *click* means "point the window cursor on a particular object and click with the *left* mouse button.")

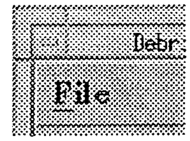
The interface for DAW consists of windows containing options that allow the user to input program control and data input specifications. Most options are identified within the window by a text label describing the option's function or the parameter to be input. In some circumstances, options may be deactivated and inaccessible to the user. For such cases, the text label is shown dimmed (or grayed) on the screen. The interface also employs the basic object-oriented concept of using the right mouse button to produce a pop-up menu containing items specific to the window object clicked upon. Several standard window conventions used to select an option or input data are summarized below.

Command button -- A rectangular button with a text label placed directly upon the button. The command to be activated is indicated by this label. To activate the option, simply click on the button.



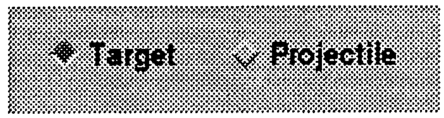
Ellipsis option -- A text label option followed by an ellipsis (**...**). Activation of this option invokes the on-screen appearance of an underlying window containing further related commands and input options. To activate the option, simply click on the text label.

Menu bar option -- A word option listed in a window's menu bar located below the window title bar. Clicking on a menu bar option invokes a pull-down menu with one or more labeled options. To select a menu item, simply click on it.

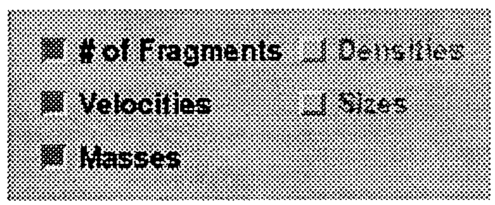


Radio button -- A small *square* or *diamond-shaped* button used to activate or deactivate (in toggle fashion) an option whose function is given by the text label placed immediately to the right of the button. An activated option is indicated by a depressed and highlighted (i.e. colorized) button. A raised, non-highlighted button indicates a deactivated choice. To toggle, simply click on the button. The two types of radio buttons, distinguished by shape, indicate the type of choices possible.

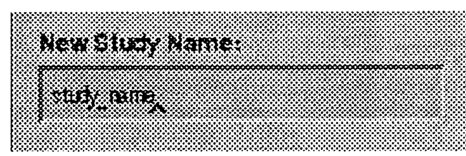
The diamond-shaped button is used to make a *mutually exclusive* choice among two or more related options:



The square button is used to activate a *mutually inclusive* choice among a group of related options. Multiple choices may be made up to the maximum number of related options (or, in certain instances, up to a software-limited number of related choices wherein the remaining choices are inaccessible as indicated by dimmed text labels):



Text entry box -- A rectangular, recessed region for entering alphanumeric data. To input a value, click within the box to obtain a cursor and type the value.



Pop-up menu -- A small pop-up menu that appears near the current cursor position whenever the *right* mouse is clicked on a *sensitive* window object such as a form, text entry box, or the window title bar. The object-oriented menu will contain options specific to the object upon which the right mouse button was clicked. To select an item in the pop-up menu, simply click on it.

In all DAW 0.1 windows there are will be, at a minimum, two menu bar options: **File** and **Help**. Since a help utility has not yet been developed, the **Help** item is currently inactive in all windows (as indicated by a dimmed label). Under the **File** option, one or more menu items may be listed including the **Close** menu option. (In some windows, this is the only option under **File**.) Clicking on **Close** will close the current window returning control to the previous window or to the system if in the initial **Debris Analysis Workstation** window (see section 2.2).

Note: *Do not attempt to close a window by using the window manager quit or close function. In Motif, this function is accomplished by double-clicking on the control-menu button located in the extreme upper left-hand corner of the window frame. In Open-Look, this is done by selecting Close from the pop-up menu generated by clicking the window title bar with the right mouse button. Doing so eliminates information needed to reconstruct the window. To properly close a* *window using either window manager in DAW, select the Close item under the File menu bar option.*

2.2 Debris Analysis Workstation Window - Starting DAW

To start DAW 0.1, go to the directory containing DAW 0.1. At the UNIX command line prompt, type **daw** to run the program. A small window entitled **Debris Analysis Workstation** like that shown in Figure 2-1 will be displayed on the screen desktop.

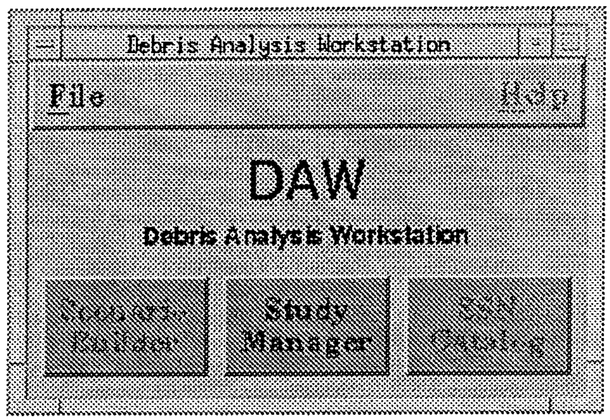


Figure 2-1. **Debris Analysis Workstation** Window.

DAW window options are described below:

File

Invokes a pull-down menu containing the following option:

Close -- Exits DAW 0.1 and closes the **Debris Analysis Workstation** window, removing it from the screen. Command is returned to the UNIX shell window or prompt.

Scenario Builder

Invokes the scenario builder process that constructs and saves study scenarios. (This option is still under development and therefore not available for DAW 0.1.)

Study Manager

Invokes the study manager needed to build, run, and examine the output from a study.

SSN Catalog

Invokes the process needed to access the Space Surveillance Network catalog of debris objects tracked and catalogued by the U.S. ground-based radar network. Models to be added to DAW in later versions will require access to this source of data. (This option is still under development and therefore not available for DAW 0.1.)

2.3 Study Manager Window

To activate the **Study Manager** window click on the **Study Manager** command button in the **Debris Analysis Workstation** window (section 2.2). The **Study Manager** window shown in Figure 2-2 will pop-up on the screen desktop.

The **Study Manager** allows the user to create a new study or load a previously run and saved study. The **Study Manager** window lists the names of all currently saved studies that it finds in its directory structure. If there are no studies listed in the **Study Manager** list box, the user *must* create a new study.

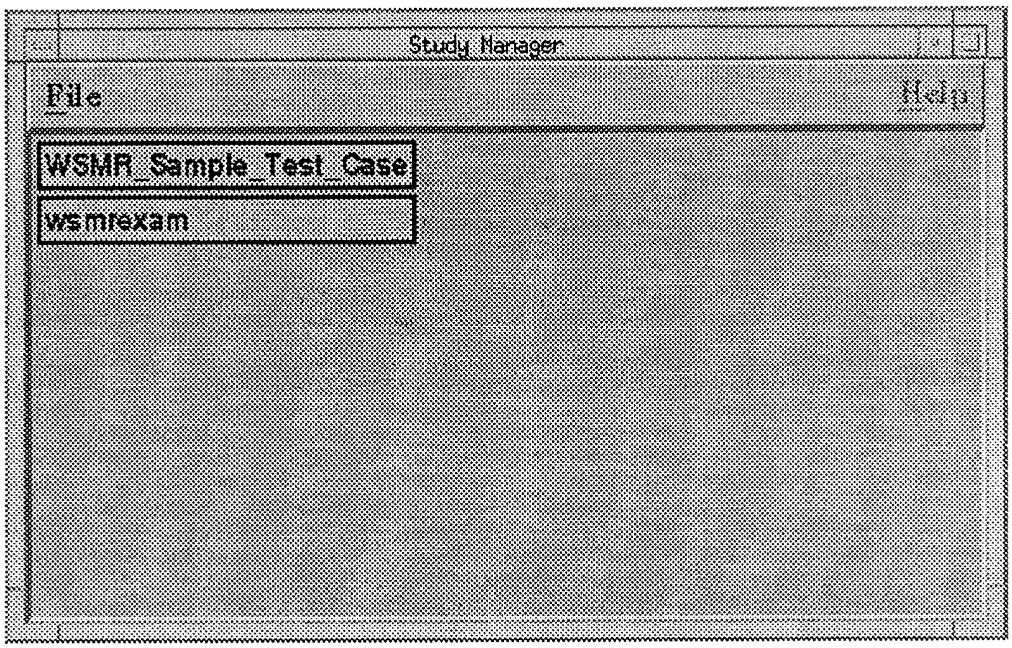


Figure 2-2. **Study Manager** Window.

The following commands are available in the **Study Manager** window:

File

Invokes a pull-down menu containing the following options:

New Study -- Creates a new study with a user-specified name. A pop-up dialog box entitled **Study Name** (Figure 2-3) is displayed prompting the user to name the new study in a text box. The name may be any valid UNIX filename. No spaces are allowed in the name. To separate words use an underscore character. Click on the **OK** command button to accept the name and invoke the **Study** dialog box (section 2.4) or click on **Cancel** to quit and return to the **Study Manager**.

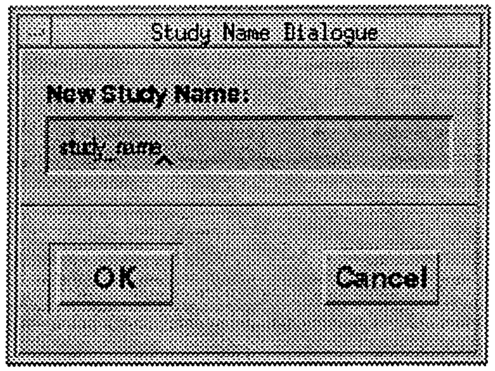


Figure 2-3. **Study Name** Dialog Box.

Close -- Closes the **Study Manager** window, removing it from the screen. This command will also close any currently opened studies.

Study window object-oriented commands

Clicking the right mouse button on any study name list invokes a miniature pull-right menu that contains options pertinent to the study selected. This menu provides the following three options:

Open

Loads the selected study into a new **Study** window (see next section) on the desktop.

Rename

Prompts the user to rename the selected study. A pop-up dialog box entitled **Rename Study** is displayed. Enter the new study name and then click **OK** to accept the new name or **Cancel** to quit without renaming. The study name is renamed in the **Study Manager** list and control is returned to the **Study Manager** window.

Delete

Displays a dialog box requesting the user to confirm whether the selected study is to be deleted. To delete the selected study from the disk, click the **OK** command button. The study name is removed from the **Study Manager** list and control is returned to the **Study Manager** window. To cancel the delete request, click the **Cancel** command button. No action is taken and control is returned to the **Study Manager** window.

2.4 Study Window

Once a study has been created or selected in the **Study Manager** (Section 2.3), the **Study** window is displayed. If the study is newly created, this window will appear as shown in Figure 2-4(a). If the study selected was previously saved, any model components that were utilized in the study will be displayed. An example is shown in Figure 2-4(b). In the **Study** dialog box, the user selects the analysis functions needed to build a specific DAW study. The analysis models perform specific tasks at each step of a study and require a specific sequence of operation. Each analysis function is called a *component* and is represented by a *component form* within the **Study** window. At present, DAW 0.1 incorporates the

IMPACT 4.0 fragmentation, FOOTPRINT debris propagation/footprint, COLLISION DISPERSION model components.

The **Study** window is divided into two functional areas. The top portion of the window provides general information about the study to be processed. The study name, execution status, edit status, and user-supplied notes are provided here. The bottom section is reserved for displaying selected model component forms (see section 2.4.1).

As shown in Figures 2-4(a) and 2-4(b), the **Study** window provides the following options:

File

Invokes a pull-down menu containing the following options:

New Comp -- Adds a new model component form to the **Study** window (below any previously created forms). Selecting this menu option invokes a pull-right menu containing a list of DAW model choices. From this list, the user selects the model to be associated with the new form. DAW 0.1 contains only two options: **IMPACT** and **FOOTPRINT**.

Save -- Saves the entire study under the current study name to the disk overwriting the previously saved study. The study remains active in DAW.

Save As -- Saves the entire study under a new name supplied by the user. A pop-up dialog window (Figure 2-3) is displayed requesting the user to input a new study name. Type the name in the text box and then click **OK** to save. To cancel and return to the **Study** window without saving, click **Cancel**. The study remains active in DAW.

Close -- Closes the current active DAW study, returning to the **Study Manager** window. If any modifications were made in the study being closed, a warning box like that shown in Figure 2-# is displayed indicating this condition and requesting the user to confirm his decision to close the current study. To confirm, click the **Close** button. The study will be closed discarding any modifications made during the active study session. To cancel and return to the active study, select **Cancel**.

Execute

Invokes a pull-down menu containing the following options:

Step -- Executes a single study component form. The form that is executed is the *next* form in the numerical sequence of form numbers (see section 2.4.1) whose execution status is either **Not Executed** or **Inconsistent**. The process is completed when the component form finishes execution (as indicated by the **Executed** status). If no eligible forms are found (i.e. all forms in the study show an **Executed** status), no action is taken and control is returned to the **Study** window.

Note: *This option cannot be used to single out a particular study component form for execution. The form to be executed will always be the next form in sequence whose status is either* **Not Executed** *or* **Inconsistent**.

<u>G</u>o -- Automatically executes in sequence all model component forms comprising a study. The execution sequence is determined by the numerical sequence of form numbers (see section 2.4.1). The process is completed when the last form finishes execution (as indicated by the **Executed** status). Barring any input errors, selecting **<u>G</u>o** ensures that a completed study will be obtained (as indicated by a **Complete** message in the **Study** dialog box status field).

Name:

Name of the current study as input in the **Study Manager**. If any modifications have been made either directly by the user or indirectly as a result of executing study components while in the **Study** dialog box or any of the model component dialog boxes since the study was last saved, the edit flag **...Modified...** will be displayed following the study name.

Status:

Provides the *execution* status of the current study. Until a study has been completely run end-to-end, an **Incomplete** message will be displayed. If a study has been completed, either during the current session or in a previous session, the message **Complete** will be displayed. For a study to be considered completed, the inputs and outputs between the various components comprising the study must be internally consistent.

Notes:

Provides a text entry box for input of study notes. A vertical scroll bar is provided to scroll the text, if needed. If the study is later saved, any notes entered will be saved with the study.

Component Form List

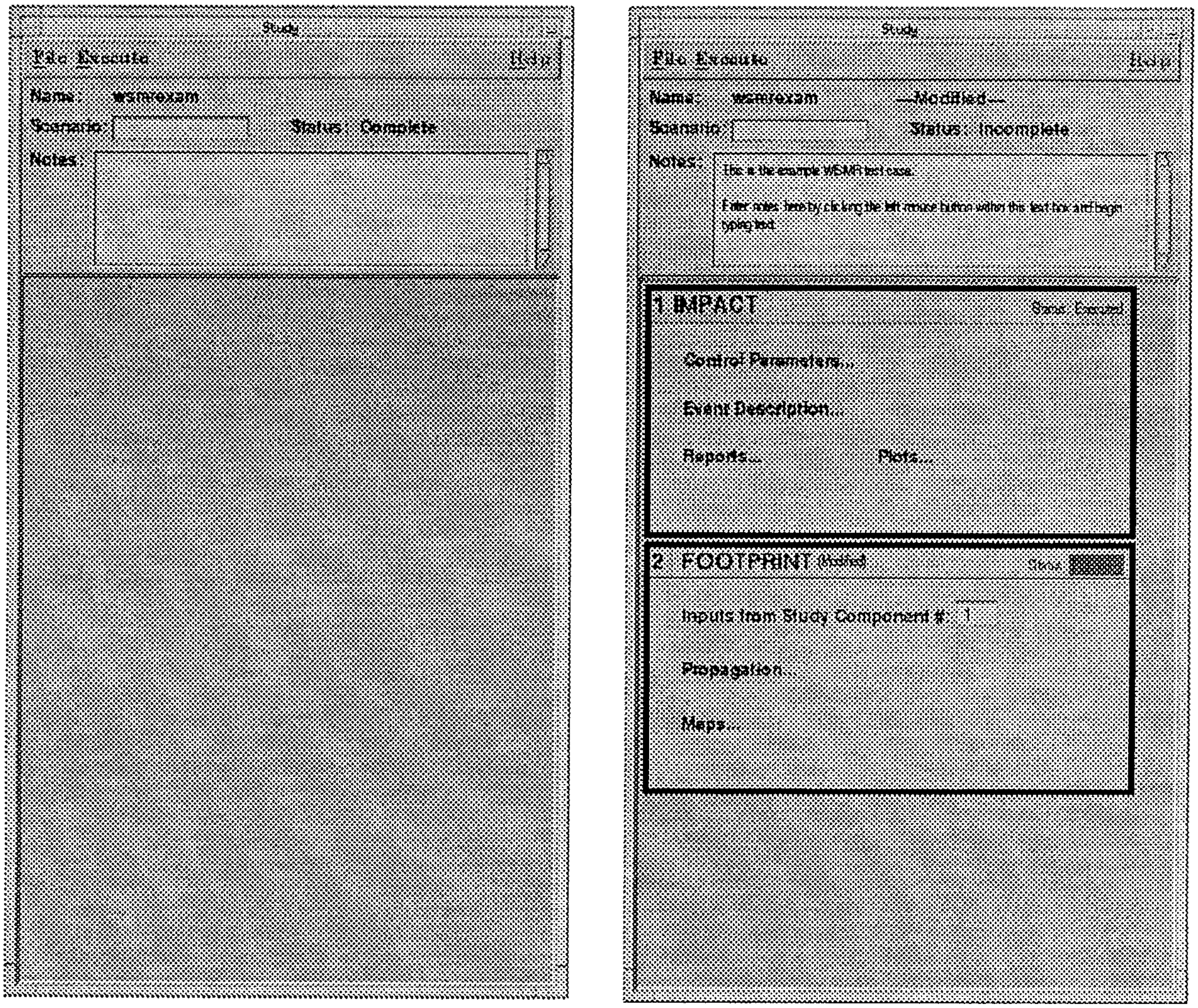
The bottom section of the **Study** window is reserved for placement of all component forms selected for the current study. (For a more detailed description of component forms, see section 2.4.1.) Forms are placed from top to bottom in the order that they are generated. A newly-generated study will have no forms as shown in Figure 2-4(a). Figure 2-4(b) shows two component forms that have been added to the **Study** window by the user. If there are more component forms than can be displayed within the current bounds of the **Study** window, a vertical scroll bar will appear on the right side of the window frame. This bar allows access to those forms not visible in the current window.

2.4.1 Model Component Forms

A *model component form* is the topmost specification level for the model in a study. It is from the component form where the user may access underlying windows for input of model specific information. Currently, DAW 0.1 supports only the **IMPACT** (see section 2.5) and **FOOTPRINT** (see section 2.6) model forms. Forms are added to the **Study** window as explained in section 2.4. Figure 2-4(b) shows both form types residing within the **Study** window.

The top bar of a form displays a sequentially-assigned component number, the component model name (**IMPACT** or **FOOTPRINT**), the edit status, and the execution status of the component. The component number displayed in the upper left-hand corner of the form uniquely identifies the model component.

The execution status of each model component is displayed in the upper-right corner of a component form. One of four messages may appear:



(a) (b)

Not Executed -- Model component is newly created and has not yet been executed.

Figure 2-4. **Study** window (a) as it appears when it is first invoked, and (b) after **IMPACT** and **FOOTPRINT** component forms have been added.

Executing -- Model component is currently executing. Once execution has completed the execution status message changes to **Executed**.

Executed -- Model component has completed execution. Data files created by the component execution will be available to other components or to the user for examination.

Inconsistent -- If *anything* within the model component dialog box or underlying dialog boxes has been modified by the user, or if inputs generated from the outputs of another component have changed, this message will be displayed. This condition results when inputs/outputs between model components are now inconsistent. The component must be processed again to receive the properly terminated **Executed** message.

The FOOTPRINT model requires IMPACT fragmentation model results as data input. Consequently, a **FOOTPRINT** component form *must be associated* with a specific **IMPACT** component form. Furthermore, the associated **IMPACT** form must be executed *before* the **FOOTPRINT** form is processed. More than one **FOOTPRINT** form may be associated with a single **IMPACT** form. The links between a **FOOTPRINT** form and its associated **IMPACT** form is selected by the user in the **Inputs from Study Component #:** option of the **FOOTPRINT** form (see section 2.6).

Note: *In DAW 0.1, the user is responsible for ensuring that the run sequence between an* **IMPACT** *form and one or more successive* **FOOTPRINT** *forms is properly entered. A program error will result if a* **FOOTPRINT** *form is executed without obtaining the output results of a previously executed* **IMPACT** *form.*

2.5 IMPACT Component Form

An **IMPACT** component form shown in Figure 2-5 is added to the study component list by selecting the **IMPACT** menu item under **New Comp** in the **File** menu bar option of the **Study** window. Each new selection creates a new **IMPACT** form with the next available (or sequential) component number.

Refer to section 2.4.1 for a generic description of the DAW model component forms. The options specific to the **IMPACT** form are summarized below. Additional detailed information may also be found in

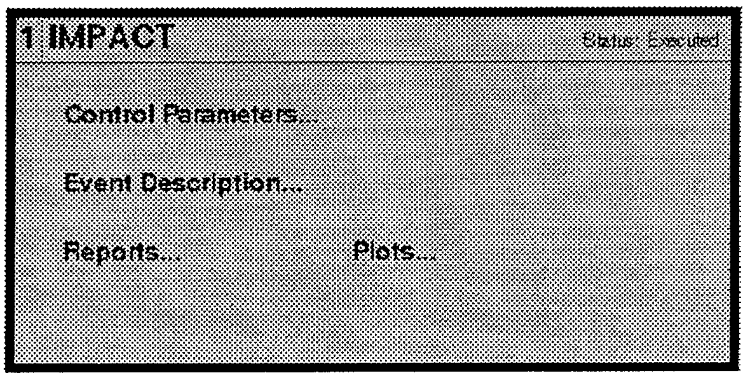


Figure 2-5. **IMPACT** Component Form.

sections 2.5.1 - 2.5.4.

Control Parameters...

Clicking on this option invokes the **IMPACT Control Parameters** pop-up window where IMPACT model control parameters are entered. These parameters specify general control options for performing the IMPACT model study. Refer to section 2.5.1 for a more detailed description of this window and its available options.

Event Description...

Clicking on this option invokes the **IMPACT Event Description** pop-up dialog box where the breakup event information needed as input to the IMPACT model is entered. Refer to section 2.5.2 for a more detailed description of this window and its available options.

Plots...

Clicking on this option invokes the **IMPACT Plot Selection** window used to request plots of output data once an **IMPACT** component has been executed. Refer to section 2.5.4 for a more detailed description of this window and its available options.

2.5.1 IMPACT Control Parameters Window

IMPACT determines *distributions* of important fragment parameters such as mass, size, and perturbed (ejecta) velocity distributed among preset data bins defined by mass. These distributions characterize the population of fragments produced in a breakup event as a whole and are derived from empirical numerical functions. If specified, the IMPACT model will also determine fragmentation parameters for *individual* (i.e. discrete) fragments predicted to occur in the event being modeled. These calculations are intended to supplement the information obtained in the parameter distribution data, being determined in addition to the distribution calculations. The discrete fragments used in these calculations are essentially culled from the same "population" of fragments whose parameter data is characterized in the IMPACT model distribution output.

To perform such calculations, the IMPACT model requires certain control information from the user specifying the conditions under which these calculations are to be run. This information includes

- Type of additional data to evaluate for individual fragments produced in the breakup event (velocity, rotation rates, dimensions)

- Minimum size threshold of fragments to be considered in the both individual and distribution calculations

- Total number of discrete fragments to considered along with number limitations of how they are distributed among the available mass bins.

- Mass bin index of a mass bin if only the fragments within a single mass bin are to be considered for individual calculations

The latter three bulleted items control what set of discrete fragments are to be considered for the individual fragment calculations. These options specify the general number and size range of the fragments to be employed (i.e., fragments may be drawn from either a single mass bin or from a range of multiple mass bins).

These control parameters are entered from the **IMPACT Control Parameters** window shown in Figure 2-6. This window is invoked by clicking the **Control Parameters...** option in the **IMPACT** component form of the **Study** window. The options found in this window are described below.

Random Number Seed:

The initial random number seed used for IMPACT processing. The fragment spread velocity magnitude and directions are randomly selected according to the velocity distributions contained in IMPACT. If nothing is modified, two consecutive executions of the **IMPACT** model would yield exactly the same fragment distribution results. To change the results in random fashion between two different runs, the random number generator starting seed must be changed. This number may be any real number.

Individual Fragment Calculations:

Options for individual fragment calculations include the state vector (breakup ECI position), post-breakup ECI velocity, spread (perturbed) velocity, rotation rate, and dimensional data (width, height, and thickness). for each individual fragment. These choices are given by the respective selection buttons labeled **Velocities**, **Rotation Rates**, and **Dimensions**. Any combination of these calculations (from none to all) may be selected for processing.

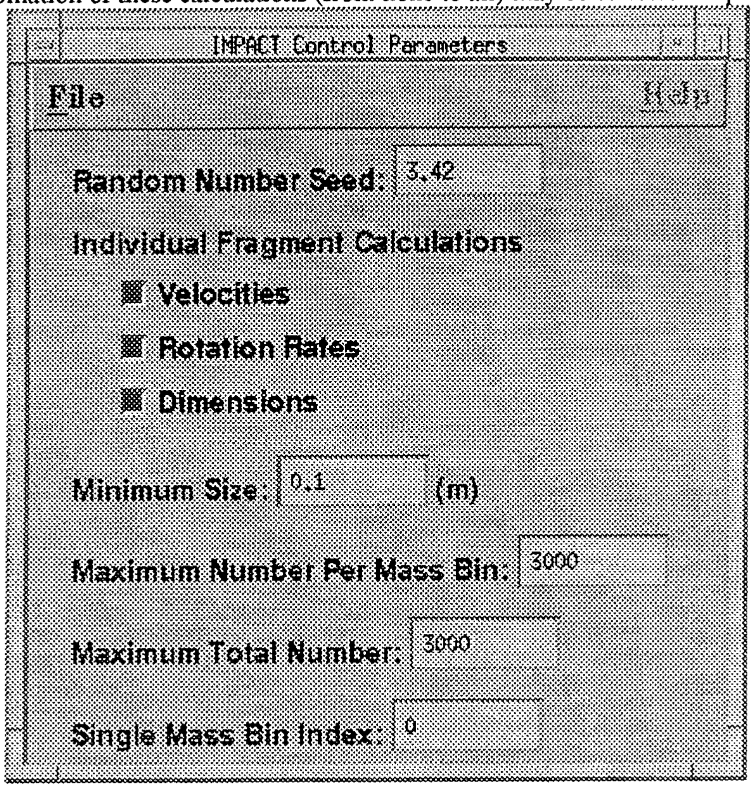


Figure 2-6. **IMPACT Control Parameters** Window.

Note: *The option* **Velocities** *must be selected if* **FOOTPRINT** *component is to be run, and* **Dimensions** *must also be selected if a drag-inclusive propagator within the FOOTPRINT model is to be used (see section 2.6).*

If at least one of these options is selected, the remaining fields in this window are used to define what part of the debris distribution is handled and reported as individual fragments for the specified calculations.

Note: *For multiple mass bin processing, the first three conditions set by these remaining inputs* (**Minimum Size:**, **Maximum Number Per Mass Bin:** , *and* **Maximum Total Number:**) *are all in force and IMPACT follows whichever condition is met first in its processing. If the user chooses values within the normal reasonable range for each option, IMPACT will calculate where to gather the individual fragments among the various mass bins. By setting the inputs on two of these options beyond their normal selection range, the user can use the remaining option as the sole discriminator for selecting the individual fragments. Examples of the latter approach are given in the following specific descriptions of these options.*

Minimum Size:

The minimum characteristic fragment diameter (in meters). In IMPACT, the characteristic size is derived as a function of three factors: (1) the characteristic mass value of the associated bin, (2) the average density of materials assigned to fragments found in this bin, and (3) the most probable dimensions of fragments assigned to this bin (as derived from dimensional distributions contained in the model). (Ref. 2) This input serves as a size cutoff where all fragments of this size or larger will be processed as individual fragments. Since fragments are binned according to mass (and therefore characteristic size) in IMPACT, fragments in mass bins whose associated characteristic size equals or exceeds the specified minimum size will be included. If this size cutoff falls within the size range for a bin, *all* fragments in this bin will be subject to the individual fragment calculations. This ensures that all fragments larger than the cutoff will be included, but may also mean that some of the remaining fragments lower than the cutoff value which reside in this bin will also be included.

For single mass bin processing (i.e. non-zero **Single Mass Bin Index:** value), this condition will not be invoked.

Example: If it is desired to model *all* fragments above a certain size as discrete fragments, then set **Minimum Size:** to the desired minimum size, set **Maximum Number Per Mass Bin:** to a very large number (e.g. 100,000), and set **Maximum Total Number:** to a very large number (e.g. 1,000,000). In this case the **Minimum Size:** option can be used to adjust the size of the individual calculation fragment set.

Maximum Number Per Mass Bin:

The maximum number of individual fragments that can be assigned to any one mass bin. This value applies equally to all mass bins regardless of characteristic mass. IMPACT gathers the individual fragments starting with the mass bin having the largest characteristic mass and proceeding through smaller mass bins until a single mass bin having greater than this number of fragments (if any) is reached. If such a condition is found, further fragment collection processing is stopped. There is no maximum value limit to this number.

Note: *If this value exceeds the number of fragments predicted by the IMPACT mass/number distribution, the number of fragments will instead be limited by this distribution value. In this case, fragment collection processing is not halted.*

For single mass bin processing (i.e. non-zero **Single Mass Bin Index:** value), this condition will not be invoked.

Maximum Total Number:

The maximum total number of fragments of all masses that will be selected for discrete fragment calculations. In multiple mass bin mode of operation (i.e. a zero **Single Mass Bin Index:** value), IMPACT starts with the largest mass bin and gathers individual fragments through sequentially smaller bins, stopping if this total number is reached. Regardless of what this number is set to, the total number of individual fragments gathered will not exceed the total number predicted by the IMPACT distribution.

For single mass bin processing (i.e. non-zero **Single Mass Bin Index** value), this number sets a limit on the maximum number of fragments within the mass bin specified by the **Single Mass Bin Index:** option. The maximum *possible* number of fragments is the total predicted by the IMPACT breakup model mass/number distribution for the mass bin characteristic value.

Note: *Whether a single mass bin or multiple mass bins are chosen, there is no maximum limit to this value, but it should be noted that practical concerns such as limited computer disk storage space and computation time would necessarily limit this number to a realistic value.*

Example: If a user desires to model the 500 largest fragments as discrete fragments regardless of what mass bin they reside in, then set **Maximum Total Number:** to 500, set **Minimum Size:** to a very small size value (e.g. 0.0001), and set **Maximum Number Per Mass Bin:** to a very large number (e.g. 100,000). In this case the **Maximum Total Number:** can be used to adjust the size of the individual calculation set.

Single Mass Bin Index:

An array index value of a mass bin used to select all fragments contained within that mass bin for individual fragment calculations. Current IMPACT mass distributions use thirty-one mass bins. Table 1 provides the characteristic mass value for each bin as denoted by an integer bin index. If this input is a positive non-zero integer less than or equal to 31, only the fragments from the mass bin whose bin index is given by this number are subject to individual fragment calculations. If this value is zero, then a multiple mass bin range is assumed and the ensemble of discrete fragments are assembled according to the **Minimum Size:**, **Maximum Number Per Mass Bin:**, and the **Maximum Total Number:** options discussed above.

Note: *If set to a valid bin index value, the* **Minimum Size:** and **Maximum Number Per Mass Bin:** *options above no longer have meaning; consequently, they are ignored by* IMPACT.

Table 1. Mass Bin Indices.

Bin Index	Characteristic Mass (kg)
1	10000.0
2	5000.0
3	2000.0
4	1000.0
5	500.0
6	200.0
7	100.0
8	50.0
9	20.0
10	10.0
11	5.0
12	2.0
13	1.0
14	0.5
15	0.2
16	0.1
17	0.05
18	0.02
19	0.01
20	0.005
21	0.002
22	0.001
23	0.0005
24	0.0002
25	0.0001
26	0.00005
27	0.00002
28	0.00001
29	0.000005
30	0.000002
31	0.000001

2.5.2 IMPACT Event Description Window

The **IMPACT Event Description** window shown in Figure 2-7 is invoked by selecting the **Event Description...** option in the **IMPACT** component dialog box of the **Study Window**. Input specifications of describing the breakup event are entered interactively within this window. Inputs include the type of breakup (collision or explosion), breakup position, target and projectile pre-event velocities, and various energy and mass parameters pertinent to the breakup event. The options found in this dialog box are described below.

<u>Breakup Type:</u>

Input the type of breakup event that IMPACT shall process. Only one type of event may be processed for each execution of the **IMPACT** component.

Click on the **Collision** command button to select a collision event to model. A collision as modeled by IMPACT involves two vehicles (target and projectile) which physically collide at hypervelocity which is generally defined as being a relative velocity in excess 2-3 km/s. In a collision, the "target" is the larger mass vehicle and the "projectile" is the smaller mass vehicle. The suitability of IMPACT to model the fragmentation event becomes increasingly less reliable as the collision relative velocity decreases below the hypervelocity range.

Click on the **Explosion** command button to choose an explosive breakup event. An explosion involves only a single vehicle (target) whose fragmentation occurs from a sudden energy release such as a tank pressure burst or a fuel detonation.

Time:

Input the epoch (date and time) at which the breakup event occurs. The epoch is needed to determine orientation of the breakup position relative to the surface of the earth. The epoch is entered in terms of the year, month, day, hour, minute, and second via six consecutive labeled text entry boxes:

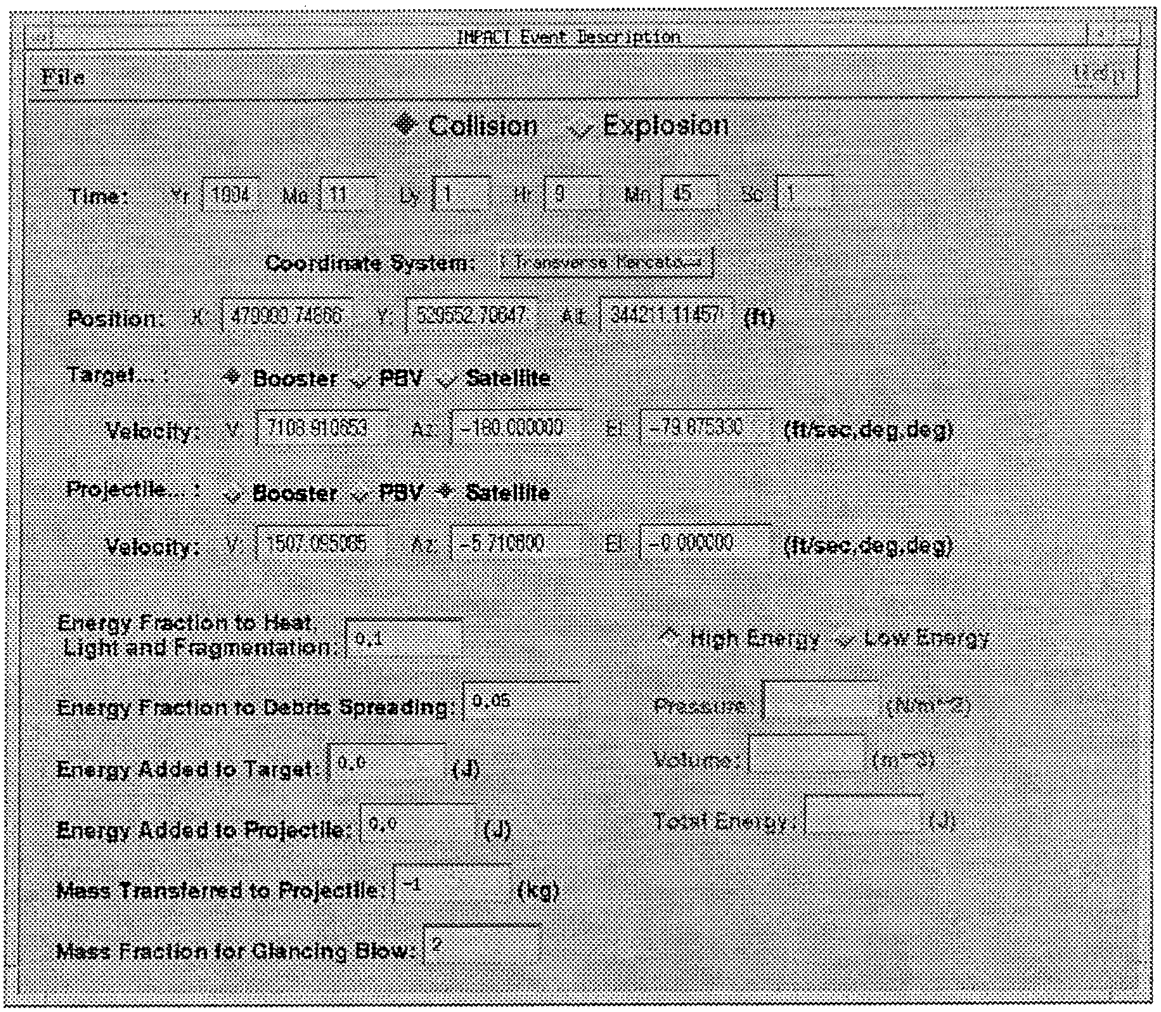


Figure 2-7. **IMPACT Event Description** Window.

Yr -- Calendar year (e.g. 1994). (Integer greater than zero.)

Mo -- Calendar month number. (Integer between 1 and 12, inclusive.)

Dy -- Day number within the month. (Integer between 1 and the maximum number of days in the month, inclusive.)

Hr -- Hour. (Integer between 0 and 23, inclusive.)

Mn -- Minute. (Integer between 0 and 59, inclusive.)

Sc -- Second. (Integer between 0 and 59, inclusive. No fractional seconds.)

Coordinate System:

Input the choice for coordinate system in which to enter the breakup position and velocity of each vehicle involved in the breakup event at the breakup position. The field of this option shows the currently active coordinate system name. Clicking this field invokes a pop-up menu of all available choices. DAW 0.1 currently has five coordinate systems to select from:

- **ECI (Vernal Equ.)** (Earth Centered Inertial, relative to point of Aries, vernal equinox)
- **Geodetic Earth Relative** (Geodetic system relative to geoid surface)
- **Geographic** (Geodetic system relative to Earth's center)
- **WS Transverse Mercator** (U.S. Army White Sands Missile Range coordinate system)
- **WS Cartesian System** (U.S. Army White Sands Missile Range coordinate system)

A detailed explanation of each coordinate system is found in section 4.1. When a system is selected, the dialog box entries for the breakup point position and vehicle velocities are automatically updated to reflect the proper parameters and units. All internal calculations in IMPACT are performed in the ECI coordinates; thus, if any of the other four coordinate systems are selected, coordinate transformations are performed before model execution. Furthermore, if coordinates are entered in the dialog box entries for position and velocity, and a different coordinate system choice is made, the values will be redisplayed in the new coordinate system coordinates and units. There may be slight differences due to numerical roundoff errors if coordinates are converted and then converted back to the original system.

Position:

Input the position in space where the fragmentation event occurs. Three coordinate inputs are required for each coordinate system. The coordinates are entered by typing the appropriate values in three consecutive text boxes. The coordinates and their units are determined by the coordinate system selected (see the **Coordinate System:** option above):

ECI (Vernal Equ.) – **X, Y, Z** Cartesian position coordinates (all in meters)

Geodetic Earth Relative	--	**Lat** (latitude in degrees) **Lon** (longitude in degrees, 0° Greenwich meridian) **Alt** (altitude above the Earth's geoid in feet)
Geographic	--	**Lat** (latitude in degrees) **Lon** (longitude in degrees, 0° Greenwich meridian) **Alt** (distance from the Earth's center in feet)
WS Transverse Mercator	--	**X** (east-west coordinate in feet) **Y** (north-south coordinate in feet) **Alt** (altitude above the Earth's surface in feet)
WS Cartesian System	--	**Easting** (east-west coordinate in feet) **Northing** (north-south coordinate in feet) **Alt** (altitude above the Earth's surface in feet)

The two sections following the **Position:** option on the **IMPACT Event Description** dialog box are reserved for inputs specific to the vehicles involved in the breakup event. As shown in Figure 2-7, the two sections are differentiated by an option (**Target...** or **Projectile...**) whose name identifies which vehicle the section is reserved for in the dialog box. The following three groups of dialog box options, then, are identical except for the vehicle being characterized. Note that if the **Explosion** breakup event type is selected (see <u>Breakup Type</u> option category above), the projectile option section is deactivated as indicated by dimmed option items on the dialog box.

Target... or **Projectile...**

Clicking one of these options invokes a pop-up dialog box where the particular vehicle's physical characteristic can be interactively input. Clicking on **Target...** invokes the **IMPACT Target Description** dialog box while clicking on **Projectile...** invokes the corresponding **IMPACT Projectile Description** dialog box. These dialog boxes are identical except for the dialog box window title stating which vehicle the box is providing inputs. Refer to section 2.5.2.1 for a more detailed description of this generic dialog box and its available options.

<u>Vehicle Structure Type</u>

Input the structural type of the vehicle. IMPACT models three general types of targets to account for varying breakup process behavior. (For a more detailed description of structural types and their effect on the breakup distributions, see Refs 1 and 2.) The target type is selected in this option category by clicking the command button next to the desired choice (highlighting the button). Only one type may be selected at a time. The individual options available are summarized below.

Booster

Selects the *booster* structural type. This category characterizes vehicles that are relatively hollow and constructed with fairly thin walls (e.g. a booster stage). Vehicles in this category tend to fragment into a few very large pieces and a relatively small number of smaller fragments.

PBV

Selects the *PBV* structural type. This category characterizes vehicles which are relatively solid (compared to the booster category) yet have large appendages that remain largely intact after a fragmentation. These pieces are more generally referred to as intact components (IC). This category is essentially a hybrid of the **Booster** and **Satellite** categories. (This category name stems from the use IMPACT routines in modeling post-boost vehicles (PBV) carrying one or more re-entry vehicle (RV) warheads as found on large intercontinental ballistic missiles. The dense RV's generally remain intact after the PBV fragments.)

Satellite

Selects the *satellite* structural type. This category characterizes vehicles which are relatively solid with no large cavities or open volumes. Vehicles in this category tend to produce a larger number of small fragments with few very large pieces produced (as is the case for the **Booster** category).

Velocity:

Input the target pre-event trajectory velocity vector coordinates. The trajectory may be either orbital or sub-orbital. Three coordinate inputs are required in all five possible coordinate systems. The coordinates are entered by typing the appropriate values in three consecutive text boxes. The coordinates and their units are determined by the coordinate system selected (see the **Coordinate System:** option above):

ECI (Vernal Equ.) -- V_x, V_y, V_z Cartesian velocity coordinates (all in m/sec)

Geodetic Earth Relative -- **V** (velocity magnitude in feet/second)
Az (velocity azimuth direction in degrees, measured clockwise from North)
El (velocity elevation direction in degrees, measured
from the local horizontal)

Geographic -- **V** (velocity magnitude in feet/second)
Az (velocity azimuth direction in degrees, measured clockwise from North)
El (velocity elevation direction in degrees, measured
from the local horizontal)

WS Transverse Mercator -- **V** (velocity magnitude in feet/second)
Az (velocity azimuth direction in degrees, measured clockwise from North)
El (velocity elevation direction in degrees, measured
from the local horizontal)

WS Cartesian System -- **V** (velocity magnitude in feet/second)
Az (velocity azimuth direction in degrees, measured clockwise from North)
El (velocity elevation direction in degrees, measured
from the local horizontal)

The next group of six dialog box options pertain to energy and mass distribution specifications to be used in the breakup process.

Energy Fraction to Heat, Light, and Fragmentation:

Input the fraction of available energy from the breakup event process "lost" to the fragmentation process itself and to other forms of energy-absorbing processes including material phase changes and heat/light production. This value represents a fraction and *must* be in the range **0.0-1.0**. Furthermore, for collisions, the *combined* value of this input and the input from the **Energy Fraction to Debris Spreading:** option below *must* also lie within the range **0.0-1.0**, inclusive. (In fact, if no other energy source is considered, the combined value should equal **1.0**.) For IMPACT, a default of **0.1** is provided.

Note: *If both this parameter and the **Energy Fraction to Debris Spreading:** below are set to zero, the program automatically determines these fractions from kinematic considerations (see section 4.3).*

Energy Fraction to Debris Spreading:

Input the fraction of available energy from the breakup event process that is available for spreading the breakup fragments. This energy corresponds to the total kinetic energy available for spreading the fragments relative to the center of mass of the vehicle debris cloud. IMPACT equipartitions this energy among all fragments predicted by the model's mass/number distribution. This value represents a fraction and *must* be in the range **0.0-1.0**. Furthermore, the *combined* value of this input and the input from the **Energy Fraction to Debris Spreading:** option above *must* also lie within the range **0.0-1.0**, inclusive. (In fact, if no other energy sink is considered, the combined value should equal **1.0**.) For IMPACT, a default of **0.05** is provided.

Note: *If both this parameter and the **Energy Fraction to Heat, Light, and Fragmentation:** below are set to zero, the program automatically determines these fractions from kinematic considerations (see section 4.3).*

Energy Added to Target:

Input additional energy (in Joules) to be included in the total available energy for the target vehicle in a collision event. This option allows for an additional energy source beyond the normal source derived from the relative kinetic energy involved in the collision. The value is simply added to the kinematically-derived energy available for spreading the target fragments. For example, this energy can be used to simulate the explosion of fuel onboard the target vehicle. This option is available only for the **Collision** breakup type and is deactivated for the **Explosion** breakup type.

Energy Added to Projectile:

Same as the **Energy Added to Target:** option above, except that the energy value is added to kinematically-derived energy for the *projectile* in a collision event. See the discussion for the **Energy Added to Target:** option above.

Mass Transferred to Projectile:

Input the mass transferred to the projectile from the target mass. This mass is transferred in the form of fragments carried away from the target by the projectile, adding to the projectile's debris cloud. Through momentum conservation, the post-collision velocities of the target and projectile clouds will be affected by the amount of mass transferred. For a more thorough discussion of the consequences of this parameter refer to Refs. 1 and 2.

To enter a value, click on the text box and type the value. The mass value must be greater than or equal to zero and less than the mass of the target. If an automatic determination for the mass transferred based on kinematic considerations (see Ref. 2) is desired, enter a value of **-1**. The default value for this parameter is **-1**.

Mass Fraction for Glancing Blow:

Input for the fraction of the total mass between both target and projectile that is subjected to the collision fragmentation process in a *glancing blow* collision. This type collision describes those collision interactions occurring when the ratio of the relative kinetic energy of the projectile to the mass of the target is low (i.e. there is not enough available energy to *completely* fragment the target via the collision process) or when it is desired to fragment only part of the available target directly through a collision process. The remainder of the mass is subjected to the explosion breakup model incorporating an exponential function to describe the number of fragments produced versus mass. The overall result is to produce a lesser number of smaller fragments with more of the mass concentrated in larger fragments.

To enter a value, click on the text box and type the value. This value represents a fraction and *must* be in the range **0.0-1.0** if the glancing blow condition is to be exercised. If a standard collision (where the entire target mass is handled by the collision breakup model) is desired, input any number greater than or equal to one. This input is provided a default value of **2.0** which results in a standard collision. This type of breakup will be automatically run for low energy collisions by the IMPACT model.

The next group of four dialog box options (an option category and three text entry options) request inputs necessary if an explosion event is to be processed. These items are activated only when the **Explosion** breakup type option is selected (see the Vehicle Structure Type option category above).

Explosion Type

Select the type of explosion to process. In the IMPACT model, there are two types of explosions, high-intensity and low-intensity, which are differentiated by the source and magnitude of the energy used to fragment an vehicle. The explosion is selected in the dialog box by clicking on the respective **High Energy** or **Low Energy** command button (highlighting it). Only one type may be selected at a time.

A high-energy explosion results from a chemical detonation or deflagration of a substance within the exploding vehicle. The overall available energy for spreading the debris fragments tends to be large resulting in higher fragment ejected velocities. The higher energy also tends to cause a larger number of smaller fragments to be produced although the overall mass distribution of fragments is still characterized by an exponential law function. The total explosive energy for such an event is directly input in the **Total Energy:** option described below.

A low-energy explosion generally results from a process such as a pressure-burst rupture of an onboard containment tank found on boosters and missiles. In such events, the contained gas suddenly expands increasing the internal pressure beyond the burst pressure of the tank, rupturing the tank, and producing a small number of mostly larger more massive fragments. This type of explosion may also result from the shock-wave induced fragmentation of the residual mass of an vehicle not directly in contact with a more energetic fragmentation source such as a high-intensity explosion or collision. In a glancing blow collision, for example, the residual mass not involved in the collision process is assumed to fragment in a low-intensity explosion-like manner. Like the high-intensity explosion, the low-intensity explosion fragment mass distribution obeys an exponential law function; however, the total explosion energy is generally less than in a high-intensity event resulting in fewer but larger more massive fragments. Since most low-intensity explosions are a result of a self-induced tank rupture, the total explosive energy for such an event is input via two parameters, tank pressure and volume, in the respective **Pressure:** and **Volume:** options described below.

Pressure:

Input a tank *burst* pressure in Newtons/meter^2 for an assumed on-board tank of the target vehicle in a low-intensity explosion breakup event. This is the pressure of the contained gas at the time of the explosion. This parameter together with the tank volume input (see the **Volume:** option below) determine the total explosive energy needed as input in the IMPACT explosion model. This option is activated only when the **Explosion** breakup type and the **Low Energy** explosion type options are selected.

Volume:

Input a tank volume in cubic meters for an assumed on-board tank of the target vehicle in a low-intensity explosion breakup event. This parameter together with the tank burst pressure input (see the **Pressure:** option above) determine the total explosive energy needed as input to the IMPACT explosion model. This option is activated only when the **Explosion** breakup type and the **Low Energy** explosion type options are selected.

Total Energy:

Input the *total* explosive energy in Joules for a high-intensity explosion breakup event needed as input to the IMPACT explosion model. It should be noted this is not just the energy used to spread the debris fragments. It is the total energy that is reduced by the energy fractions given by the **Energy Fraction to Heat, Light, and Fragmentation:** and **Energy Fraction to Debris Spreading:** options described above. This option is activated only when the **Collision** breakup type option is selected.

2.5.2.1 IMPACT Target (or Projectile) Description Dialog Box

The **IMPACT Target Description** dialog box shown in Figure 2-8 is invoked by selecting the **Target...** option in the **IMPACT Event Description** dialog box (see section 2.5.2). Likewise, the **IMPACT Projectile Description** dialog box shown in Figure 2-9 is invoked by selecting the **Projectile...** option in the **IMPACT Event Description** dialog box. Both dialog boxes are identical in the options and inputs they offer, but they provide inputs for either the target or projectile vehicles involved in a breakup event depending on which box is selected. The dialog box window title indicates which box has been invoked.

These boxes provide the means to input specifications for the vehicle(s) involved in a breakup event. Inputs include vehicle solid and liquid masses, structural material densities and mass fractions, and structural/material specifications for major intact components found on or within the vehicle. The options accessible for interactive input depend on the structural type (**Booster**, **PBV**, or **Satellite**) specified in the Vehicle Structure Type option category found in the **IMPACT Event Description** dialog box. The current vehicle type value is displayed in the upper-right portion of the vehicle description dialog box. The options found in this dialog box are described below.

Mass:

Input the total *dry* mass in kilograms of the vehicle that is subject to fragmentation, (excluding any onboard *liquids* or *liquid* propellants). This input should include the mass of any solid propellants since they can be fragmented. The *total mass* or *wet mass* of the vehicle is this value combined with the value input for the **Liquid Fuel Mass:** option below.

The mass must be greater than zero. If the vehicle is the projectile in a *collision event* as specified by selection of the **Collision** option in the **IMPACT Event Description** dialog box (see section 2.5.2), it cannot be greater than the mass specified for the target. By definition, IMPACT considers the vehicle with the larger mass the target in a collision event.

Liquid Fuel Mass:

Input the total liquid fuel, propellant, or other storable liquid mass onboard the vehicle. The *total mass* or *wet mass* of the vehicle is this value combined with the value input for the solid **Mass:** option above.

Solid Materials:

In this section of the dialog box, specifications for the materials comprising the solid materials of the vehicle involved in the breakup event are input. Up to ten different materials can be input for a single vehicle and inputs for each material are entered in the options below each material number shown in the dialog box next to the label **Solid Materials:**. For *each material*, up to three specifications must be input and are summarized below.

Fractions:

Input the fraction of the total vehicle mass composed of a given material. The value must range from **0.0** to **1.0**. The sum of all material mass fractions must add up to one.

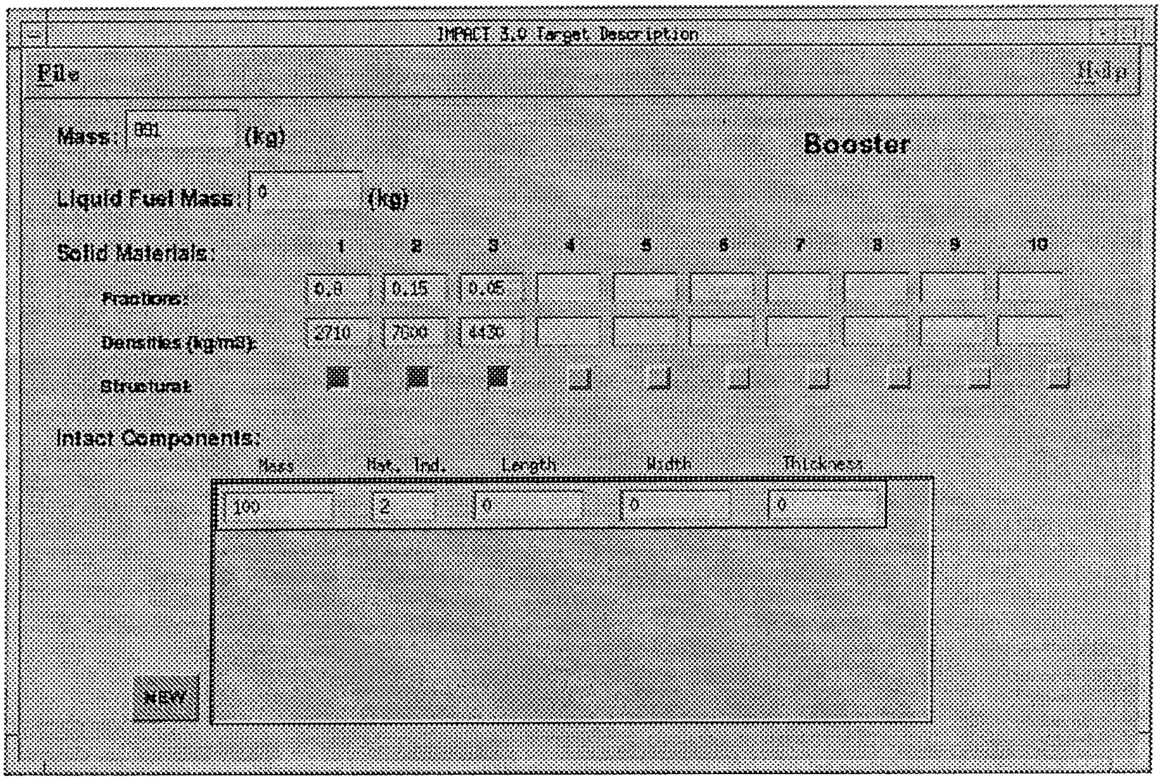


Figure 2-8. **IMPACT Target Description** Pop-up Dialog Box.

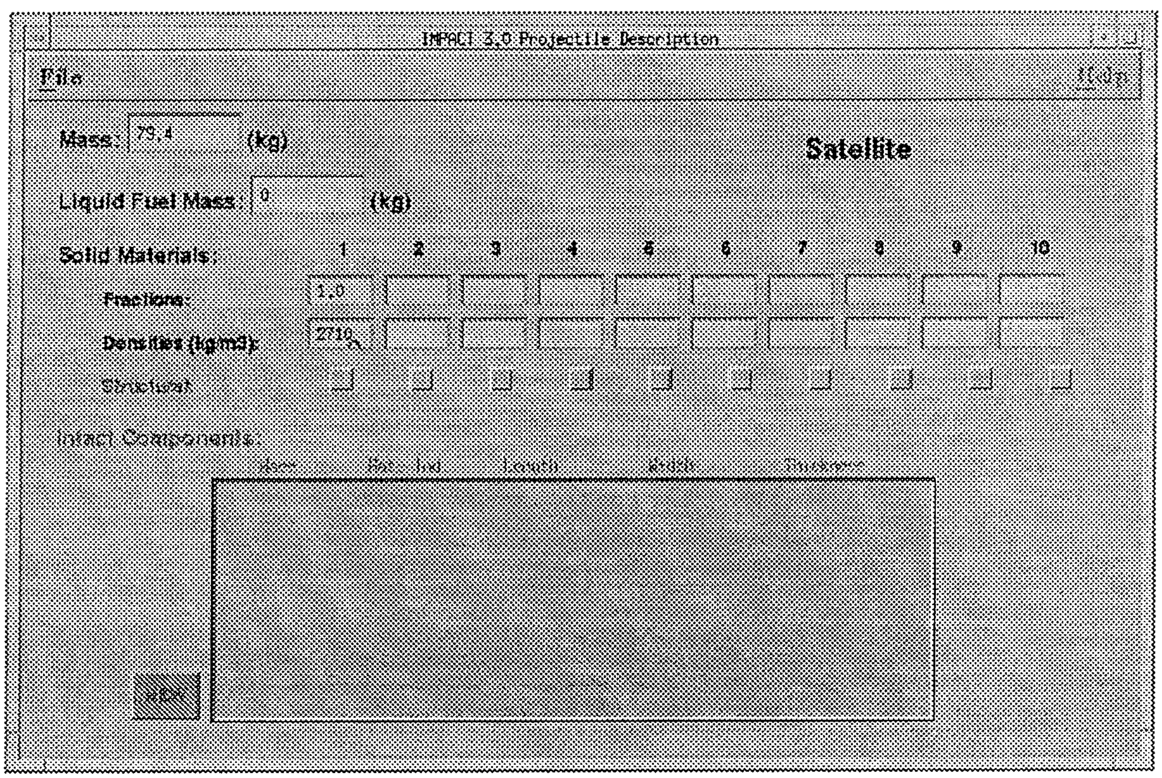


Figure 2-9. **IMPACT Projectile Description** Pop-up Dialog Box.

Densities:

Input the material density in kilograms/meter^3. Any positive value may be entered. Densities of typical materials found in orbital and sub-orbital vehicles are given in Table 2.

Table 2. Densities for Common Vehicle Materials

Material	Density (kg/m^3)
Aluminum alloys	2710-2800
Titanium Alloys	4430-4460
Steel Alloys	7600-7920
Magnesium	1770
Beryllium Alloys	1830-2100
Graphite/epoxy	1490-1690
Uranium Oxide	10960
Water	1000

Structural:

Input whether the material represents a structural material to distinguish it from non-structural materials (e.g. solid fuel mass) necessary to carry out processing for the booster vehicle type as selected by **Booster** in the Vehicle Structure Type option category in the **IMPACT Event Description** dialog box (see section 2.5.2 above). Differentiating which components are structural ensures that the large structural fragments created in the breakup process (e.g. pieces of the outer skin, tank fragments, and ends of a booster) are indeed assigned the proper material components. A minimum of one material *must* be chosen as structural. More than one material may also be selected to represent a combination of structural materials.

To assign or deassign a material as being structural, click the command button in the **Structural:** row under the material component number. The **Structural:** option is activated only for the **Booster** vehicle type.

Intact Components:

In this section of the dialog box, a large text list box is displayed capable of inputting specific information for up to fifty intact components found on the vehicle. An intact component represents those parts of a vehicle that would ordinarily break off intact in a breakup event. They could be large appendages such as thrust nozzles and solar arrays, or they could be self-contained attachable components such as re-entry vehicles (RV) found on a post-boost vehicle. The intact component masses comprise all or part of the total mass specified for the vehicle.

A row of individual blank text boxes can be inserted in the text list box by clicking the **NEW** command button near the lower left corner of the text list box. Once the text boxes are displayed, inputs can be made by clicking the desired text box and typing the value. Each intact component is characterized by five parameters. The parameter titles located above the text list box indicate the input parameter corresponding to a text box column. A single intact component data entry row may by deleted by selecting the **Delete** item in a miniature pull-down menu activated by clicking the right mouse button while the window pointer is located on the intact component text box row. The intact component row may be replicated by selecting **Repeat** from this menu.

The **Intact Component:** options are activated only for the **Booster** and **PBV** vehicle types. The intact component parameters are summarized below.

Mass

Mass of the intact component in kilograms. The value may be zero or any positive value. The mass of the intact component must be less than or equal to the available mass for the chosen material (as determined by the density of the material selected via the **Mat. Ind.** option discussed below).

Mat. Ind.

Material index or component number. This value must be a valid integer material number from the **Solid Materials:** section of the dialog box (i.e. they must have non-blank **Fractions:** and **Densities:** text boxes). This field assigns a single primary material to the intact component.

The following three options request the dimensions for each intact component if known. If set to **0**, the intact component dimensions will be treated as any other fragment whose only known quantities are mass and material density (specified by the **Mass** and **Mat. Ind.** options above. If values are input, all three dimension must be input, and it is up to the user to ensure that the volume (as determined by the **Length**, **Width**, or **Thickness** options below), the mass (as determined by the **Mass** option above), and density (as determined by the density associated with the **Mat. Ind.** option above) are self-consistent (if required). These text entry boxes must not be left blank.

Length

Length dimension of the intact component in meters.

Width

Width dimension of the intact component in meters.

Thickness

Thickness dimension of the intact component in meters.

2.5.3 IMPACT Reports Dialog Box

The **IMPACT Reports** dialog box is invoked by selecting the **Reports...** option in the **IMPACT** component dialog box of the **Study** dialog box. Here, the user may select the type of textual report descriptions of IMPACT data to display to the screen for examination. These reports are formatted from data generated by IMPACT which essentially outputs a database corresponding to each vehicle involved in the breakup process. In an explosion event, only a target database is created. In a collision breakup event, equivalent databases are created for both the target and projectile vehicles.

The **IMPACT Reports** dialog box as shown in Figures 2-10(a), 2-11(a), and 2-12(a) is organized as one large text list box where one or more **Report Description** dialog boxes can be invoked and placed within the text list box. Each **Report Description** dialog box corresponds to a particular file where the data is found. The associated file is automatically selected according to the specifications in the **IMPACT Reports** dialog box and the file name is displayed in the **Output File Name:** text entry box. These output files are those automatically generated by the **IMPACT** model component. Additional **Report Description** boxes may be added as needed by selecting **New Report** under the **File** option of the **IMPACT Reports** window menu bar. As these dialog boxes are added, they will be displayed beneath existing dialog boxes (if any). If there is not enough room to display all boxes on the **IMPACT Reports** window, a vertical scroll bar will be provided.

To *delete* any **Reports Description** generated, click on the title panel of the box (i.e. the rectangular region containing the title **Reports Description**). This invokes a miniature pull-down menu containing the **Browse** and **Delete** options. Click on **Delete** to remove the dialog box.

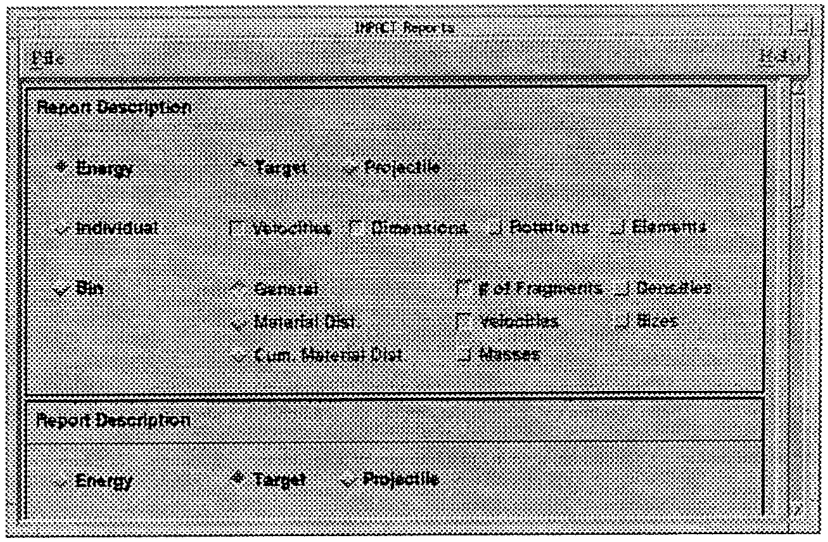
The data which may be selected in the **IMPACT Reports** dialog box is grouped into three general types. The first involves data resulting from energy distribution calculations for the breakup event. Figure 2-10(a) shows the **IMPACT Reports** dialog box specifications for an **Energy** type report using the target vehicle. The corresponding output file window is shown in Figure 2-10(b). The second data group involves data resulting from individual fragment calculations (e.g. ECI velocity vectors, post-fragmentation orbits, and fragment dimensional information). Figures 2-11(a) and 2-11(b) show the equivalent dialog box specifications and displayed output file window, respectively. The third group involves data associated with each mass bin (e.g. number of fragments, characteristic spread velocity for each bin).

Each **Reports Description** dialog box corresponds to a single ASCII file of IMPACT output data formatted according to the selections made in the dialog box. To view the IMPACT output file associated with a **Reports Description** module on a separate window on the screen, click the title panel of the **Reports Description** dialog box with the right mouse button (i.e. the rectangular region at the top of the box containing the title **Reports Description**). This invokes a miniature pull-down menu containing the **Browse** and **Delete** options. Click on **Browse** to view the file contents in a pop-up window. Figures 2-10(b), 2-11(b), and 2-12(b) show the report windows generated by the respective **Reports Description** dialog boxes shown in Figures 2-10(a), 2-11(a), and 2-12(a).

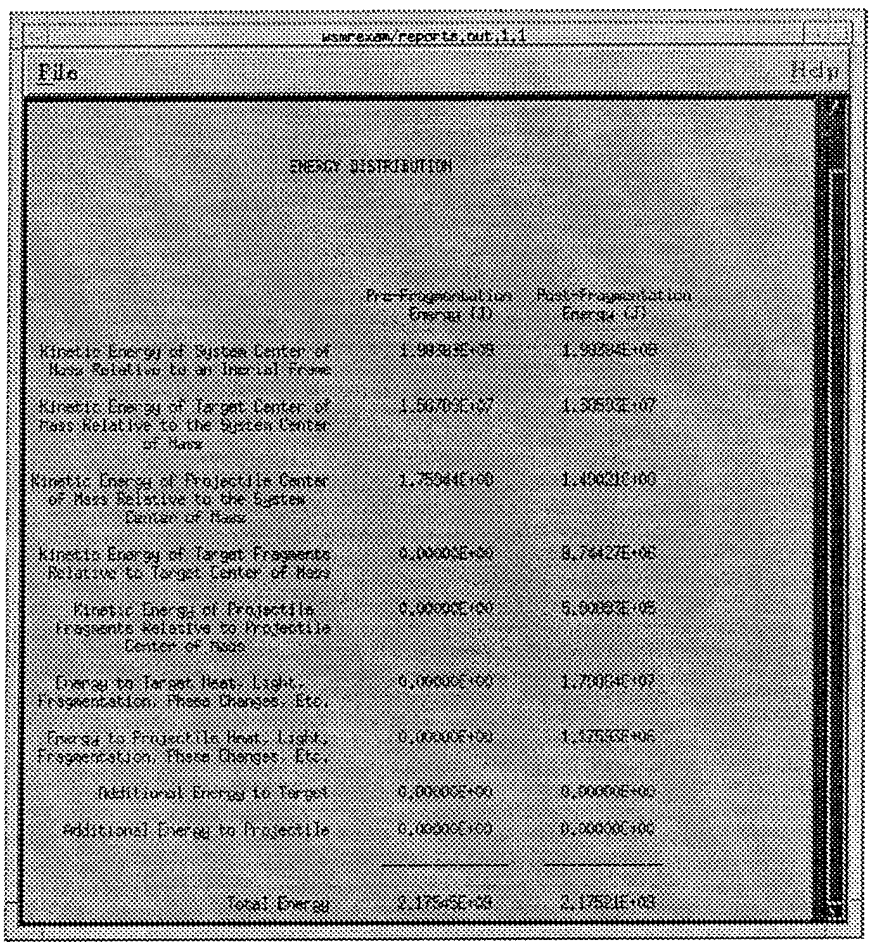
The options in the **IMPACT Reports** dialog box fall within several category groups of command buttons. These option categories and their options are summarized below.

Data Group

> The data group option category specifies which type of data report is to be reviewed on-screen. This is the top-most level required to specify a data report and *must* be specified first. The next option that must be specified is the vehicle type (see Vehicle Type category below).

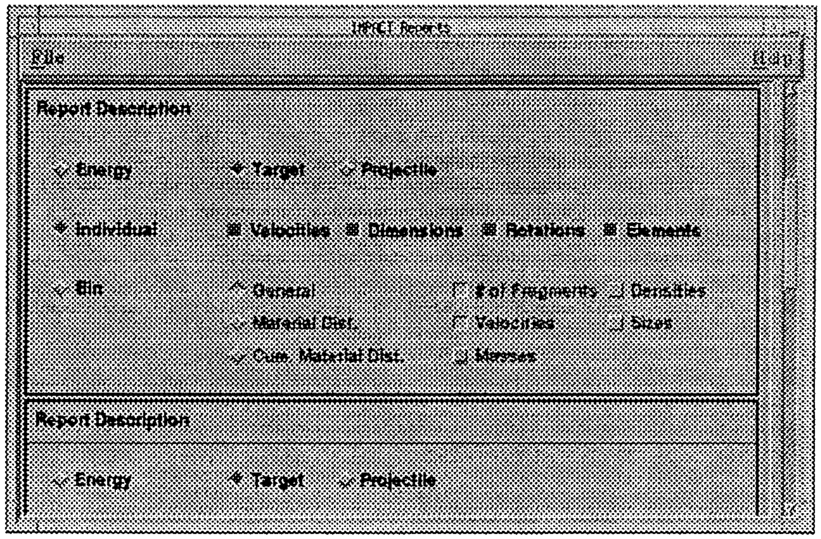


(a)

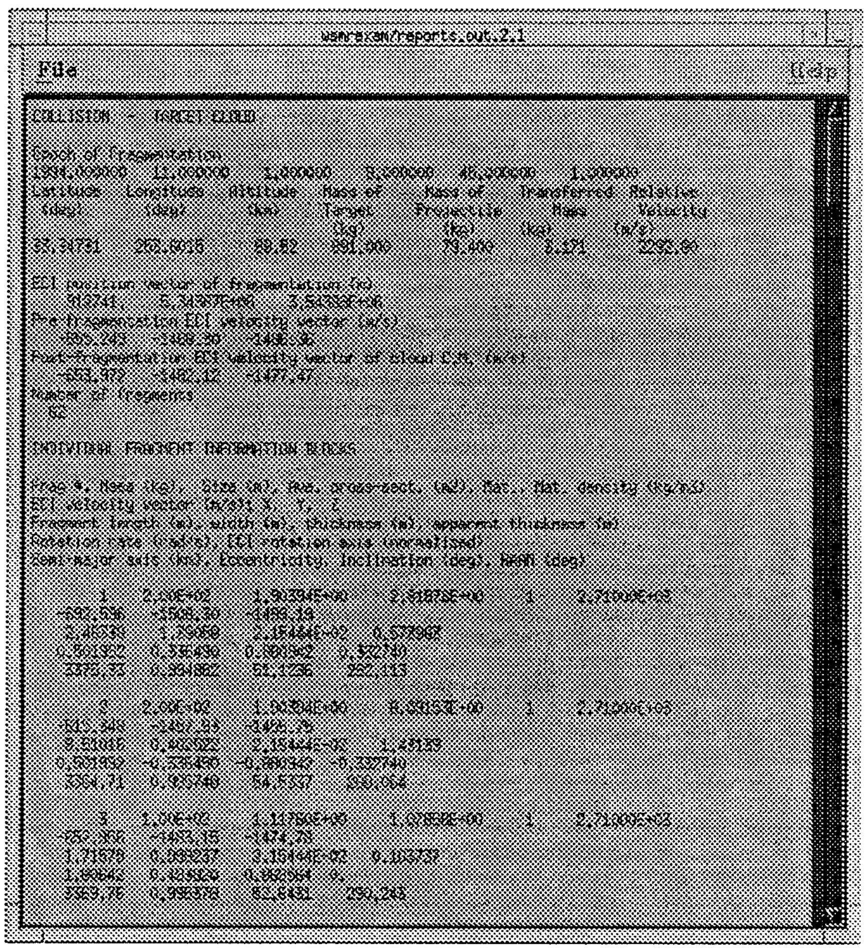


(b)

Figure 2-10. (a) **IMPACT Reports** Pop-Up Dialog Box for Energy Data Type Report.
(b) Associated On-Screen Browse Window for Data File.

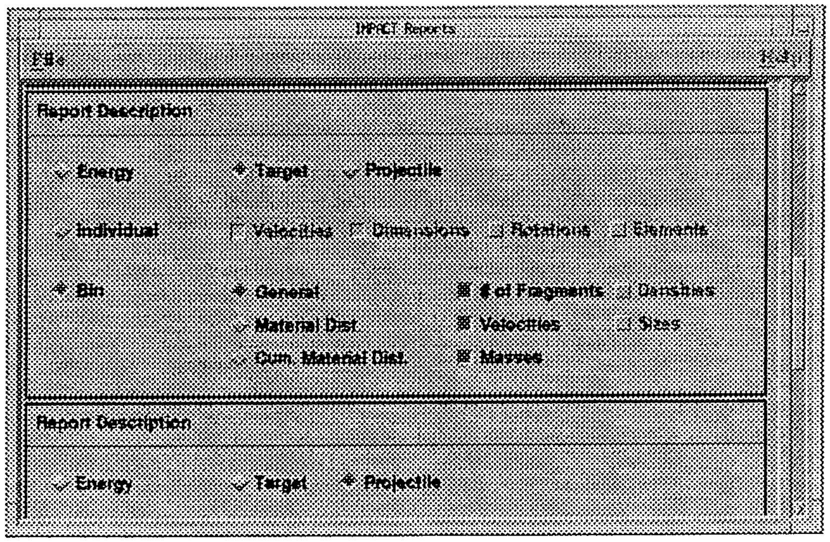


(a)

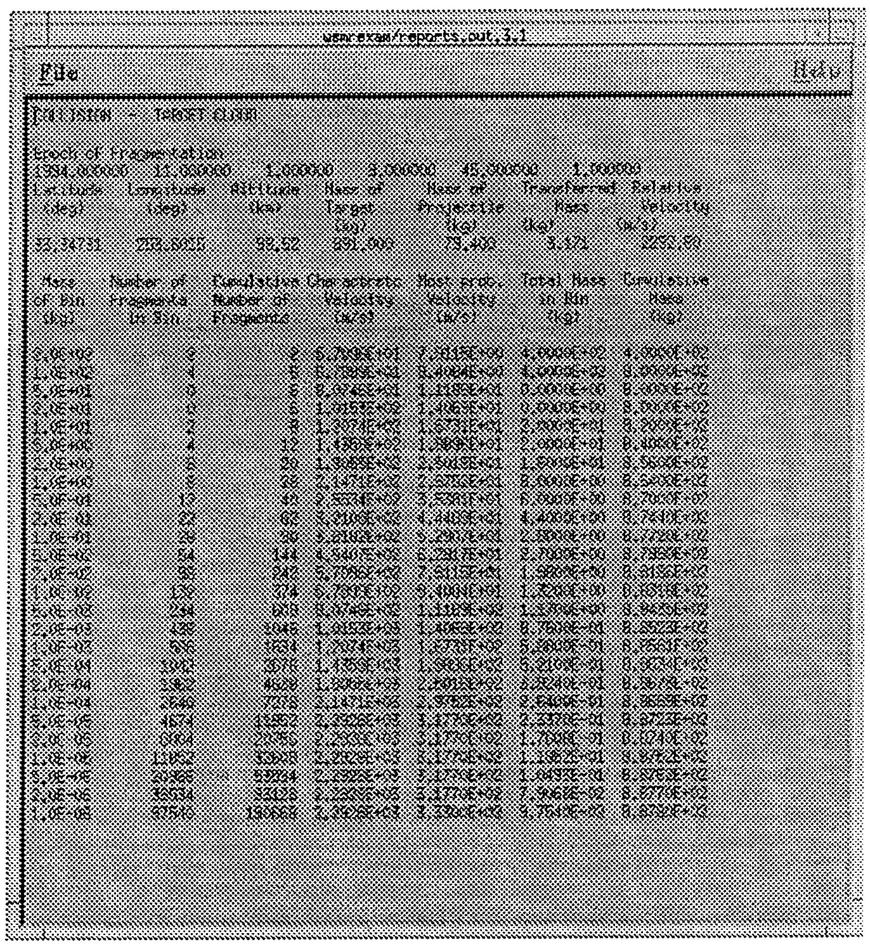


(b)

Figure 2-11. (a) **IMPACT Reports** Pop-Up Dialog Box for Individual Fragment Data Type Report.
(b) Associated On-Screen Browse Window for Data File.



(a)



(b)

Figure 2-12. (a) **IMPACT Reports** Pop-Up Dialog Box for Bin Data Type Report.
(b) Associated On-Screen Browse Window for Data File.

Energy

Select the *energy* type data report. The data that can be examined include the pre-fragmentation and post-fragmentation energy distributions for the breakup event under study. A listing is provided showing the various kinetic energies kinematically determined in the breakup and the energies lost in the dissipative processes of heat, light, etc., are provided. See Figures 2-10(a) and 2-10(b).

Individual

Select the *individual* fragments type data report. The data that can be examined include general data on the breakup event such as epoch, breakup point position, ECI position and vehicle pre-event ECI velocity vector, and post-event ECI velocity vector of the resulting debris cloud center of mass.

Blocks of data containing specific initial condition information on the individual fragments produced in the breakup event are also provided. Each data block corresponds to a single fragment. The data include physical parameters of the fragment, fragment dimensions (if specified), fragment ECI velocity vector (if specified), orbital elements (if specified), and rotation rate information (if specified), mass, size, average cross-sectional area, component material, density, and dimensions). Basic physical parameter information calculated are fragment mass, size (mean diameter), average cross section, material component, and density. See Figures 2-11(a) and 2-11(b).

<u>Options Specific to Individual Data Group</u>

This row of four options is accessible only when the **Individual** data type option is selected.

Velocities

Select whether the fragment ECI velocity vector data is included in the individual fragment block information blocks of the individual data type report. *Note:* The **IMPACT** model component *must* have be previously run with the **Velocities** option set in the **IMPACT Control Parameters** dialog box (see section 2.5.1).

Dimensions

Select whether the fragment dimensional data (length, width, thickness, and apparent thickness) is included in the individual fragment block information blocks of the individual data type report. *Note:* The **IMPACT** model component *must* have be previously run with the **Dimensions** option set in the **IMPACT Control Parameters** dialog box (see section 2.5.1).

Rotations

Select whether the fragment rotation rate and normalized ECI rotation axis are included in the individual fragment block information blocks of the individual data type report. *Note:* The

IMPACT model component *must* have been previously run with the **Rotation Rates** option set in the **IMPACT Control Parameters** dialog box (see section 2.5.1).

Elements

Select whether the fragment orbital elements (semi-major axis, eccentricity, inclination, and right ascension of the ascending node) are included in the individual fragment block information blocks of the individual data type report.

Bin

Select the *bin* type data report. The data that can be examined include general data on the breakup event such as epoch, breakup point position, vehicle(s) mass(es), transferred mass (if a collision), and relative velocity (if a collision). The report may also include tabular data providing bin characteristic mass, bin characteristic size, number of fragments/bin, cumulative number of fragments/bin, characteristic velocity associated with the mass/size bin, most probable velocity, total mass of fragments residing in each mass bin, the cumulative total mass of fragments residing in each mass bin, and the number (or cumulative number) of fragments in each mass bin characterized by mass.

<u>Options Specific to Bin Data Group</u>

This category of options specifies the columnar data to be displayed in the bin data type report.

General

Select the general bin data category for columnar information to be displayed in the bin data report. Up to three types of data may be displayed (any combination) and the selection may be made from the following five options displayed the **Report Description** dialog box: **# of Fragments**, **Velocities**, **Masses**, **Densities**, **Sizes**. For each data type, two columns are displayed in the report containing specific related information as functions of the characteristic mass bin values. Table 3 shows the columnar data displayed for each option.

Table 3. General Bin Data Type Display Options

Category Option	Column 1	Column 2
# of Fragments	Number of fragments in mass bin	Cumulative number of fragments in current and larger mass bins
Velocities	Characteristic velocity	Most probable velocity
Masses	Total mass in bin	Cumulative mass in current bin and larger mass bins
Densities	Average density of fragments in bin	Cumulative average density of current and larger mass bins
Sizes	Characteristic size (diameter)	Smallest size in bin

Material Dist.

Select the *material distribution* bin data category for columnar information to be displayed in the bin data report. In this report, columnar data displayed are mass bin characteristic value and the number of fragments in each mass bin for each material component comprising the vehicle as characterized by the material component's density. Each material component supplies one column of data in the report.

Cum. Mat. Dist.

Select the *cumulative material distribution* bin data category for columnar information to be displayed in the bin data report. In this report, columnar data displayed are mass bin characteristic value and the number of fragments in each mass bin for each material component comprising the vehicle as characterized by the material component's density. Each material component supplies one column of data in the report.

<u>Vehicle Type</u>

Indicate the vehicle database to utilize for reporting the data. This option category has only the following two options:

Target

Select the *target* vehicle database.

Projectile

Select the *projectile* vehicle database. This option is deactivated if the current breakup event type is **Explosion** (see Section 2.5.2).

2.5.4 IMPACT Plot Selection Window

The **IMPACT Plot Selection** window shown in Figure 2-13 is invoked by selecting the **Plots...** option in the IMPACT component form of the **Study Window**. In this window, the user may select the type of IMPACT results data he desires plotted in a separate plotting window. The same databases used to report the textual data (see section 2.5.3) is used to generate the plot results. The options found in this window are described below.

<u>Vehicle Type</u>

Indicate the vehicle database to utilize for plotting the data. This option category has only the following two options:

Target

Select the *target* vehicle database.

Projectile

Select the *projectile* vehicle database. This option is deactivated if the current breakup event type is **Explosion** (see section 2.5.2).

List of Plots Available

This section of the dialog box lists in option form all available data plots. One or more plot selections may be made from this dialog box by clicking on the command buttons next to the desired plot descriptions. A highlighted button indicates the choice has been selected.

After all desired plot selections have been made, click on the **Display Plot(s)** option (in the pull-down menu under **File** located in the **IMPACT Plot Selection** window menu bar) to display the plot. Each plot selected is displayed within its own plot window using the ACE/gr plotting package (Ref. 3). To generate more than one plot window simply click again on the **IMPACT Plot Selection** window to make it active and make another selection. The details of the ACE/gr generated plot window are given in Section 2.5.4.1.

Although the **IMPACT Plot Selection** window itemizes the choices available, they can be categorized according to the type of independent plot parameter (X-axis) versus a dependent parameter (Y-axis). Table 4 shows a matrix of the scatter and line plots available in DAW 0.1 for analysis of the IMPACT results. The bolded row and column titles indicate the actual labels used in the **IMPACT Plot Selection** window. Table 4 then shows the type plot (line or scatter) and the combination of dependent/independent parameter available for the plot. If the table entry is blank no plot is available. A complete description of each parameter is given in the glossary of parameter definitions following Table 4.

As an example, take the **# of Frags vs. Size** plot option given in the **IMPACT Plot Selection** window. Selecting this option means that a scatter plot of the fragment size will be plotted on the X-axis and the number of fragments will be plotted along the Y-axis.

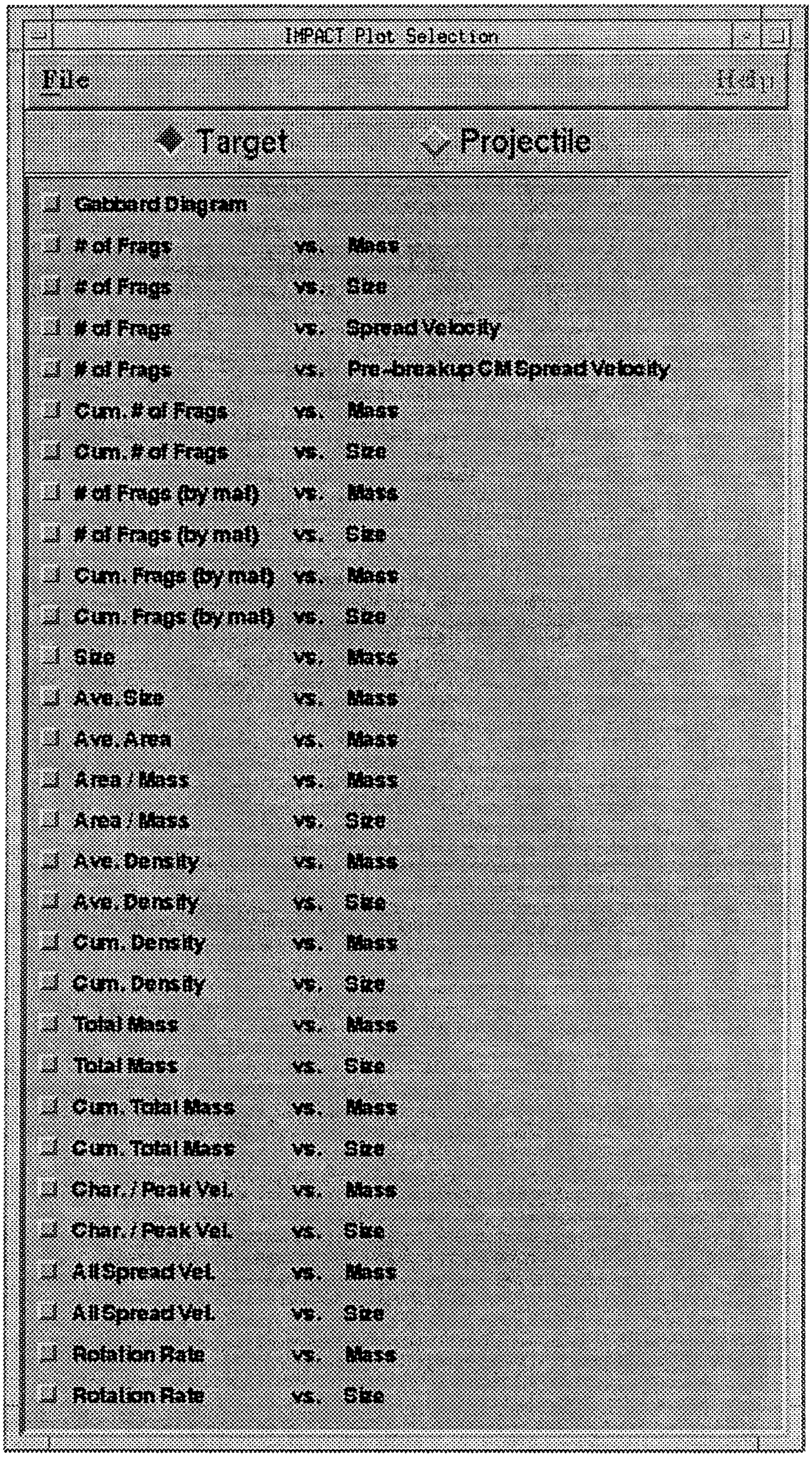


Figure 2-13. **IMPACT Plot Selection** Window.

Table 4. Matrix of Available IMPACT Data Plots

Dependent Parameter (Y-axis)	*Independent Parameter (X-axis)* Gabbard Diagram	Mass	Size	Spread Velocity	Pre-Breakup CM Spread Velocity
Gabbard Diagram	Scatter				
# of Frags		Scatter	Scatter	Scatter	Scatter
Cum. # of Frags		Line	Line		
# of Frags (by mat)		Scatter	Scatter		
Cum. # of Frags (by mat)		Line	Line		
Size		Line			
Ave. Size		Scatter			
Ave. Area		Scatter			
Area / Mass		Scatter	Scatter		
Ave. Density		Scatter	Scatter		
Cum. Density		Line	Line		
Total Mass		Scatter	Scatter		
Cum. Total Mass		Line	Line		
Char./ Peak Vel.		Line	Line		
All Spread Vel.		Scatter	Scatter		
Rotation Rate		Scatter	Scatter		

Glossary of Parameter Definitions:

All Spread Vel. All assignable spread velocity values within a bin (based on the energy equipartitioning approach discussed in Ref. 2)

Area / Mass Ratio of fragment area (assuming circular cross-section and diameter derived from IMPACT mass/size relationship) and mass as predicted by the IMPACT mass/number distribution (see Ref. 2)

Ave. Area Mean fragment area (m^2) assuming a circular cross-section averaged over all fragments placed in a bin

Ave. Density Mean fragment density (kg/m^3) averaged over all component materials and over all fragments placed in a bin

Ave. Size Mean fragment diameter (m) averaged over all fragments placed in a bin

Char./ Peak Vel. Characteristic *and* most probable spread velocities (m/s) of fragments in a bin as predicted by the MPACT breakup model characteristic and spreading function distributions (see Ref. 2)

Cum. Density Cumulative mean fragment density (kg/m^3) averaged over all materials and over all fragments placed in a bin for the current bin or larger

Cum. # of Frags Cumulative number of fragments in the current bin and larger as predicted by the IMPACT breakup model mass/number distribution (see Ref. 2)

Cum. # of Frags (by mat) Cumulative number of fragments of each user-specified material in the current bin and larger as predicted by the IMPACT breakup model mass/number distribution (see Ref. 2)

Cum. Total Mass Cumulative total mass (described in the *Total Mass* definition below) for the current bin and larger

Gabbard Diagram A Gabbard diagram is a scatter plot of fragment orbit apogee *and* perigee altitude (km) versus orbital period (min). *Note:* if a suborbital trajectory is represented, perigee values will be negative.

# of Frags Number of fragments in each bin as predicted by the IMPACT breakup model mass/number distribution (see Ref. 2)

# of Frags (by mat) Number of fragments of each user-specified material in each bin as predicted by the IMPACT breakup model mass/number distribution (see Ref. 2)

Mass	Mass bin characteristic value (kg)
Pre-Breakup CM Spread Velocity	Fragment spread velocity (see **Spread Velocity** definition below) relative to the pre-breakup center of mass velocity (m/s) of the vehicles involved in the breakup event
Rotation Rate	Individual fragment rotation rate magnitude
Size	Mean fragment diameter (m) derived from the mass bin characteristic value (kg) via the IMPACT mass/size relationship
Spread Velocity	Fragment spread (perturbed) velocity (m/s) value as predicted by the IMPACT breakup model characteristic and spreading function distributions (see Ref. 2)
Total Mass	Summed total over all fragments placed in a bin of the mass assigned *each* fragment as predicted by the IMPACT mass/number distribution (see Ref. 2)

2.5.4.1 ACE/gr Plot Window

Each selection of a plot from the itemized list in the **IMPACT Plot Selection** dialog box (Figure 2-13) generates a separate X-terminal window under control of the ACE/gr plot package (Ref. 3). Figure 2-14 shows the resulting window if the **# Frags vs. Mass** plot option is selected. All ACE/gr plot windows are entitled **xmgr**. The proper data plot will be displayed with scales automatically determined to include all data points. The plot type (line, scatter), title, axis labels, and axis types (linear, logarithmic) are initially set at the predetermined defaults for the plot selected. These parameters and others, however, may be modified using the extensive set of commands supplied by the ACE/gr package.

Note: *Except for a few general features worth noting, it is beyond the scope of this document to explain the wide variety of pull-down menus, commands, and specifiable plotting options available in ACE/gr. Please refer to the ACE/gr documentation in Reference 3 for details on the ACE/gr plotting package.*

The ACE/gr plot window as shown in Figure 2-14 has three menu bar with three options (**File**, **Edit**, and **View**) located at the top of the window and a control panel of commonly used commands to the left of the plot display. Each menu option invokes a lengthy list of menu items needed to navigate through the ACE/gr commands and features.

To *print* a hardcopy of the plot display to the default printer, simply select the **Print** item under the **File** menu bar option. (The printer set-up defaults may be modified by invoking the **Printer Set-up...** option under **File**.)

To *close* an ACE/gr plot window, click on the **Exit** command button of the control panel to the left of the plot display. The other control panel buttons are used to control plot display scrolling, zooming, and plot scaling. Please refer to section 3.5 of the ACE/gr User's Manual (Ref. 3) for an explanation of the other control panels commands of the ACE/gr plot window.

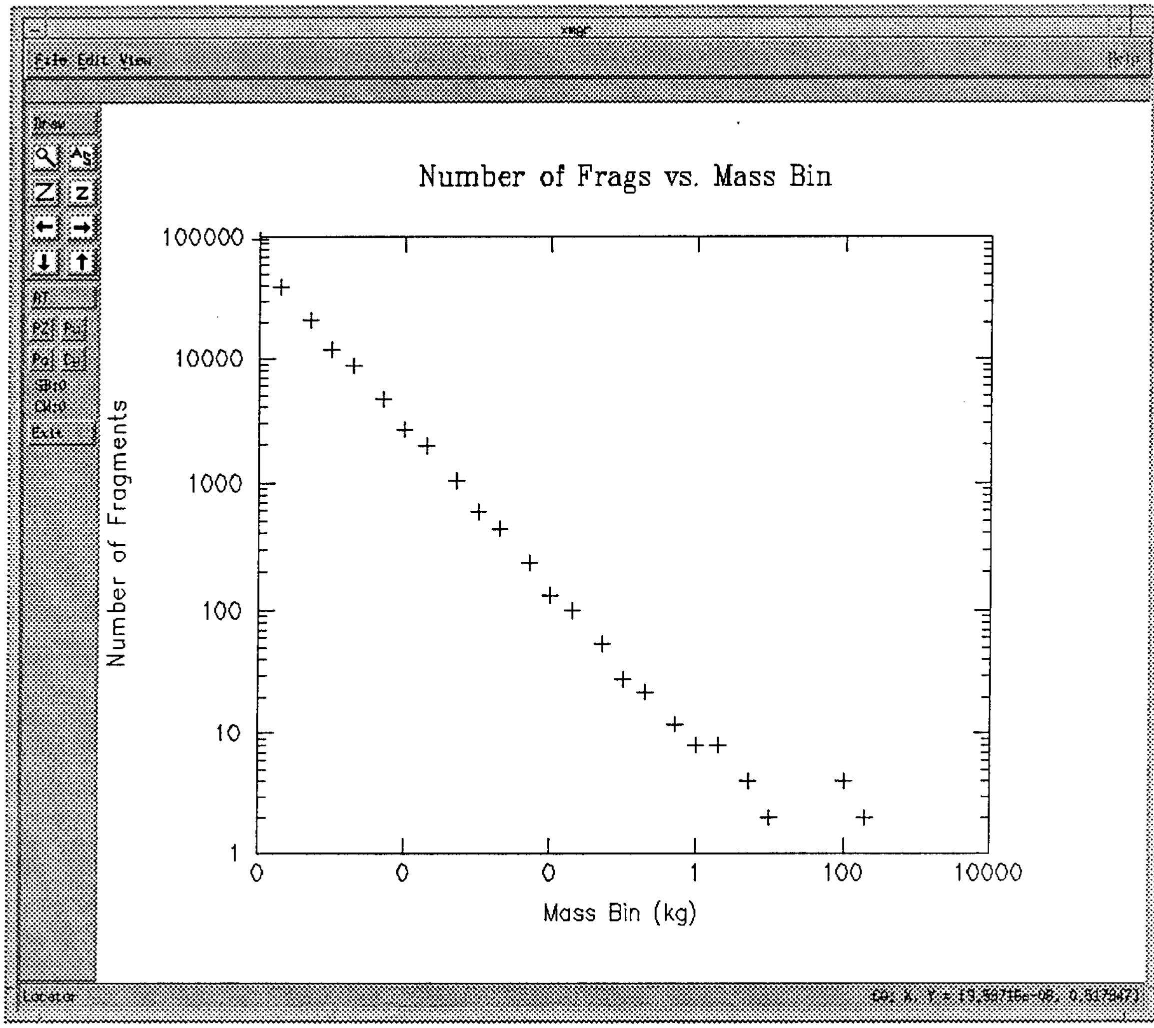


Figure 2-14. Sample ACE/gr Plot Window.

2.6 FOOTPRINT Component Form

The **FOOTPRINT** component form as shown in Figure 2-15 is invoked by selecting the **FOOTPRINT** option under **New Comp** in the **File** menu bar option of the **Study** dialog box. Each selection creates a new **FOOTPRINT** component dialog box with a component number incremented by one over the previously generated dialog box (if one exists).

The top line displays the component number, model name, and execution status of the component. The remainder of the dialog box options are intended to set-up specific FOOTPRINT run conditions and invoke the map processor to graphically display footprint results. The options are summarized below and more detailed information about the map processor may be found in section 2.6.1.

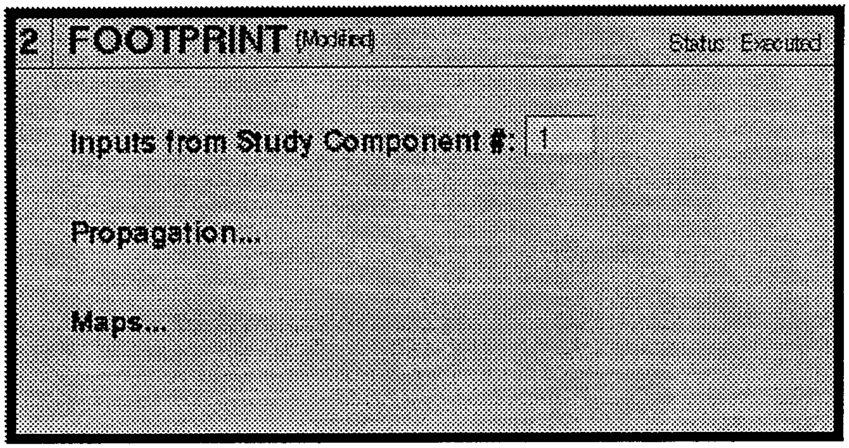


Figure 2-15. **FOOTPRINT** Model Component Form.

Inputs from Study Component #:

Input the *component number* of the **IMPACT** component whose output data will provide the debris fragment input to the FOOTPRINT propagator model. A valid component number must be given or the **FOOTPRINT** component will not execute. (See section 2.4 for a description of component numbers.)

Propagation...

Clicking on this option invokes the **FOOTPRINT Propagation** window where the user can select the propagator which determines fragment trajectories from the breakup point. Refer to section 2.6.1 for a more detailed description of this window and its available options.

Maps...

Clicking on this option invokes the **FOOTPRINT Maps** window where fragment footprint display conditions can be selected. The map displays of the footprint positions can be invoked from within this window. Refer to section 2.6.2 for a more detailed description of this window and its available options.

2.6.1 FOOTPRINT Propagation Window

In the **FOOTPRINT Propagation** window shown in Figure 2-16, the user selects which propagator model (Keplerian, atmospheric drag-inclusive, and atmospheric drag-inclusive with wind drag) is to be used to calculate the trajectory at user-specified altitude positions. Specific inputs required by the propagation models are also entered in this window. This window is invoked by selecting the

Propagation... option in the **FOOTPRINT** component form found in the **Study** window. The options found in this input window are summarized below.

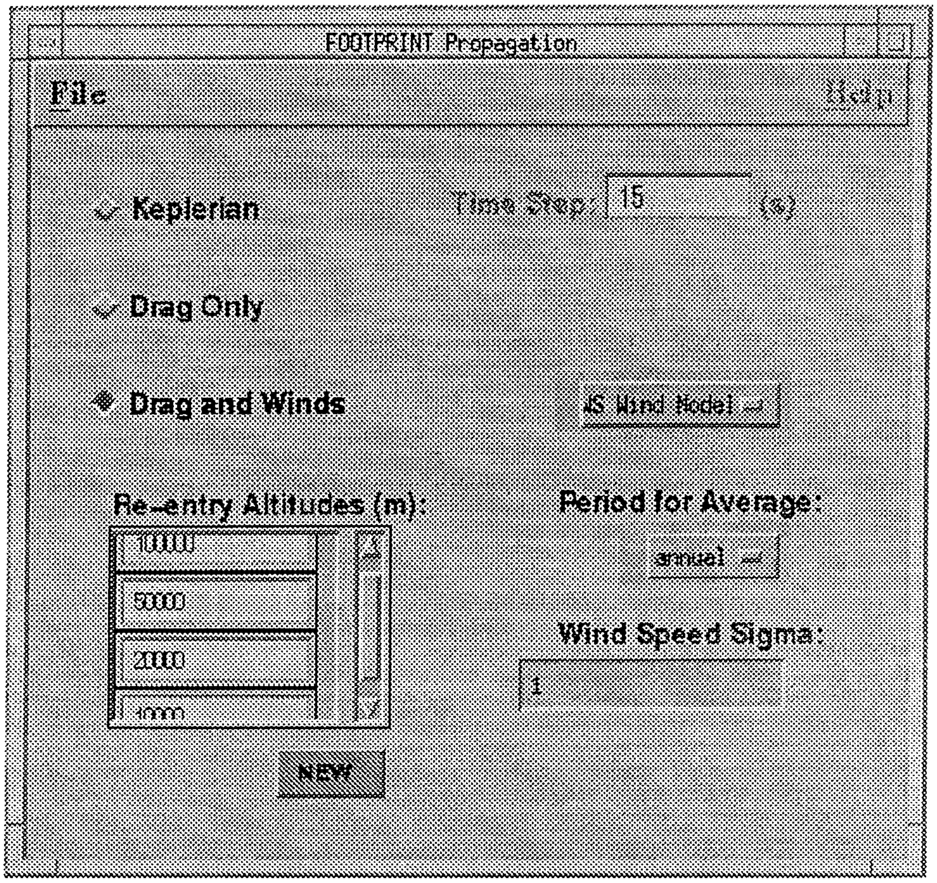


Figure 2-16. **FOOTPRINT Propagation** Window.

Propagator Model

Controls the selection of the propagator model to use in propagating the debris fragment trajectories from the breakup point to each user-specified re-entry altitude at which a footprint estimation is made. This option category has three model choices selected by clicking the desired command button. Only one model may be selected at a time. The model choices are summarized below.

Keplerian

Selects the **Keplerian** propagator for performing the FOOTPRINT trajectory calculations. This propagator calculates the Keplerian orbit resulting from the initial fragment velocity predicted by the IMPACT fragmentation model. Being an analytic model which does no integration to estimate the trajectory, this model is computationally fast. Atmospheric drag and wind effects are neglected.

Drag Only

Selects the CHICNLIL propagator model *with atmospheric (ballistic) drag only* for performing the FOOTPRINT trajectory calculations. This model does account for the effect of drag on re-entering debris fragments on the basic Keplerian orbit and integrates the equations of motion to obtain the trajectory, requiring significantly more computation time. The CHICNLIL models uses the White Sand Missile Range reference atmosphere. (See section 4.2 for a discussion of the CHICNLIL model.)

Drag and Winds

Selects the CHICNLIL propagator model *with both atmospheric (ballistic) drag and wind drag* for performing the FOOTPRINT trajectory calculations. This model accounts for the effect of ballistic drag on re-entering debris fragments and the effect of winds on the trajectory. Wind drag affects mostly the trajectories and, therefore the resulting footprint, of fragments with larger ballistic coefficients (i.e. lighter fragments with proportionately larger cross-sectional areas). The model integrates the equations of motion to obtain the trajectory, requiring significantly more computation time. The CHICNLIL models uses the White Sand Missile Range reference atmosphere. (See section 4.2 for a discussion of the CHICNLIL model.)

The wind model employed by this option is selected via the pull down menu field located next to the right of the **Drag and Winds** propagator option. Currently, the only available winds data model in DAW 0.1 is the White Sands Missile Range wind model (see section 4.2). At present, clicking on this option has no effect.

Time Step:

Input the numerical time step in seconds that the **Keplerian** propagator discussed above is used to process the trajectory positions and to determine when each re-entry altitude has been reached. The altitude of the fragment at each time step is determined from the point along the fixed Keplerian orbit to determine if the desired re-entry altitude has been reached or exceeded. If so, the position *at this time step* is noted as the footprint position. Thus, choosing a smaller time step will increase the accuracy of the footprint position (i.e. the proximate position to the re-entry cutoff altitude), but will increase the run time. The footprint position will become increasingly inaccurate as the time step is increased. For accurate results, it is suggested that time steps should be chosen to be less than 2-3% of the average orbital period of the re-entering fragment orbits. This option is activated only if the **Keplerian** propagator has been selected.

Re-entry Altitudes (m):

Input an unlimited number of re-entry altitudes in meters above the Earth's surface (geoid) required to characterize the footprints of re-entering debris fragments from a breakup event. A footprint is calculated at each valid re-entry altitude selected in the text list box.

To enter a value, click the **NEW** button beside the text list box. A blank text box will appear in the list box just below any previously generated altitude text box entries (if any). The input re-entry altitudes must not be negative or greater than the breakup point altitude. They may be entered in any numerical order. To delete any existing text entry box, click on that text box to select it and then click the right mouse button to invoke the mini-menu next to the mouse pointer. Only one option, **Delete**, is available. Click the left mouse button on this option to delete the text entry box.

Period for Average:

Clicking on the labeled button of this option invokes a pull-down menu containing seventeen items specifying a time period over which to average the wind speed data associated with the wind model specified under the **Drag and Winds** option (see above). The time period can be selected from among the following menu items.

Annual	--	Average over the entire twelve months of a year.
Spring	--	Average over the three winter months (March, April, May).
Summer	--	Average over the three summer months (June, July, August).
Fall	--	Average over the three winter months (September, October, November).
Winter	--	Average over the three winter months (December, January, February).
Jan. - Dec.	--	Average over the individual month (twelve choices possible).

Wind Speed Sigma:

Input zero or a positive integer specifying the multiple of the standard deviation (σ) with which the wind speed is allowed to vary about the average value (obtained from the wind database over the time period specified in the previous option, **Period for Average:**) in the statistical CHICNLIL model calculations for wind drag. A value of zero means the average value is always used with no variation. Otherwise, the wind speed value used in the calculations may be drawn from a Gaussian distribution up to the $\pm n\sigma$ values where n is the value of this option. Be aware that values of $n = 2$ or more greatly increase the required computation time.

2.6.2 FOOTPRINT Maps Window

The **FOOTPRINT Maps** window is invoked by selecting **Maps...** in the **FOOTPRINT** dialog box found in the **Study** window. The **FOOTPRINT Maps** window like those shown in Figures 17(a) and 18(a) requests the user to input conditions necessary to display, on a geographical map, the footprint data generated after executing a **FOOTPRINT** model component form in the **Study** window. Once the conditions have been set in this box, the map may be displayed in a separate pop-up window by selecting **Display Map(s)** under the **File** menu bar option of the **FOOTPRINT Maps** window. The details of this map window are discussed in section 2.6.2.1.

Note: *To print a hardcopy of the map plot, click* **Print** *under the* **File** *menu option of this dialog box. No print feature exists in an on-screen map window; it must be accomplished here in the* **FOOTPRINT Maps** *dialog box.*

Input conditions include specifications for displaying the map itself and the type and range of fragment data to plot. The dialog box options are summarized below.

Type:

Controls the type of geographical map view to display.

Click **Flat** to display a flat Mercator view of the map surface of the Earth placed within a rectangular on-screen view area (Figure 17(b)). This view requires a viewing position whose map center is expressed in latitude and longitude coordinates and whose distance is determined by an angular viewing range ($\Delta\theta$) in both latitude and longitude centered at the central latitude and longitude points.

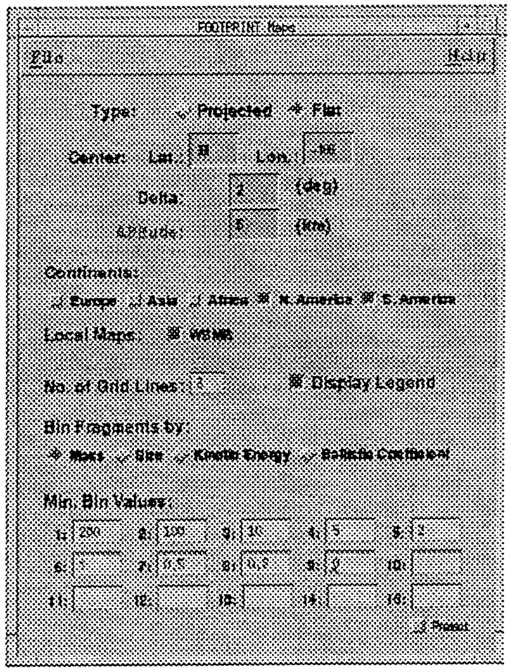
Click **Projected** to display a fish-eye-lens projected view of the map surface of the Earth (Figure 18(b)). The map will be spherically distorted so that a greater area of surface coverage can be achieved. The extent of the coverage is determined by the viewline tangent to the horizon. A constant unit of flat-screen distance will correspond to a greater geographical distance near the outer edges of the circular viewing area than at or near the center of the map view. This view requires a viewing position whose map center is expressed in latitude and longitude coordinates and whose distance is specified in terms of the altitude above the surface at the center point.

Center:

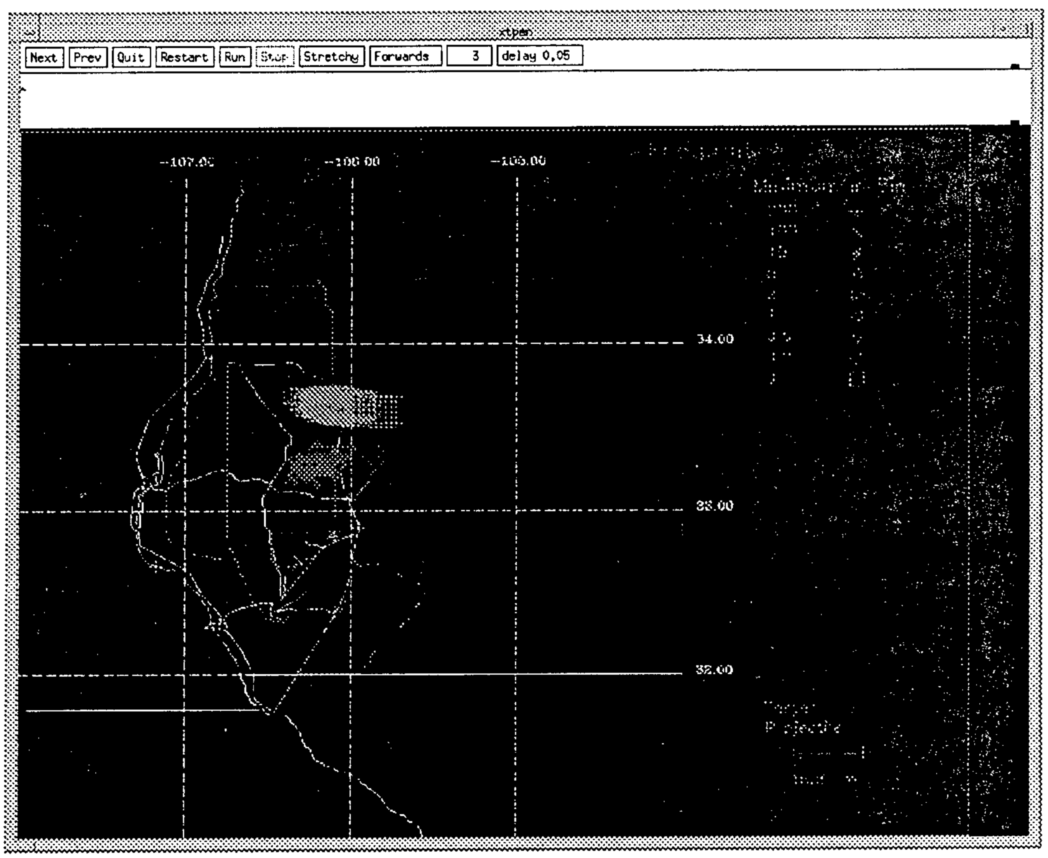
Specifies center point of the map display in terms of latitude and longitude. To enter latitude in degrees, click in the text box labeled **Lat:** and type the value. To enter longitude in degrees, click in the text box labeled **Lon:** and type the value. Longitude may be specified either east of Greenwich as a positive-valued number (e.g. 254°) or west of Greenwich as a negative-valued number (e.g. −106°).

Delta:

Input for the angular viewing range ($\Delta\theta$) in both latitude and longitude (expressed in degrees) required to produce a **Flat** map display. When the map is displayed, a rectangular map area will be shown with the angular width in latitude (vertical coordinate) and longitude (horizontal coordinate) specified by twice this value. This option is disabled if the **Projected** map type is selected. See also the **Type**: specification above. A default value has been established for this value. To enter the default value, select **Default Area** under the **File** menu bar option of the **FOOTPRINT Maps** window.

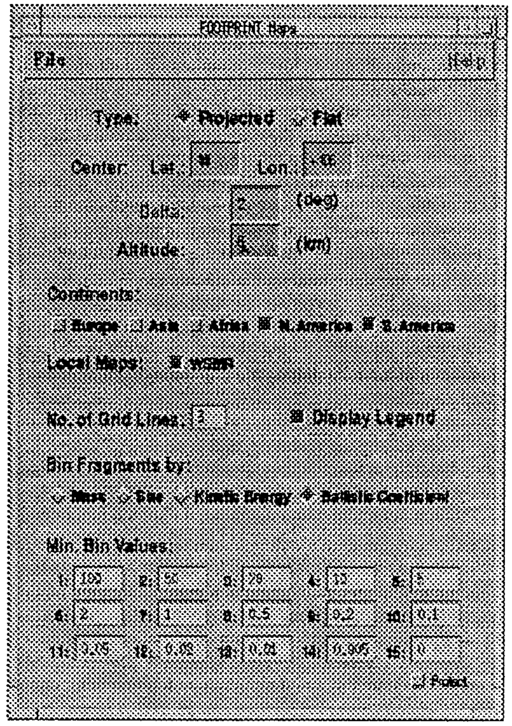


(a)

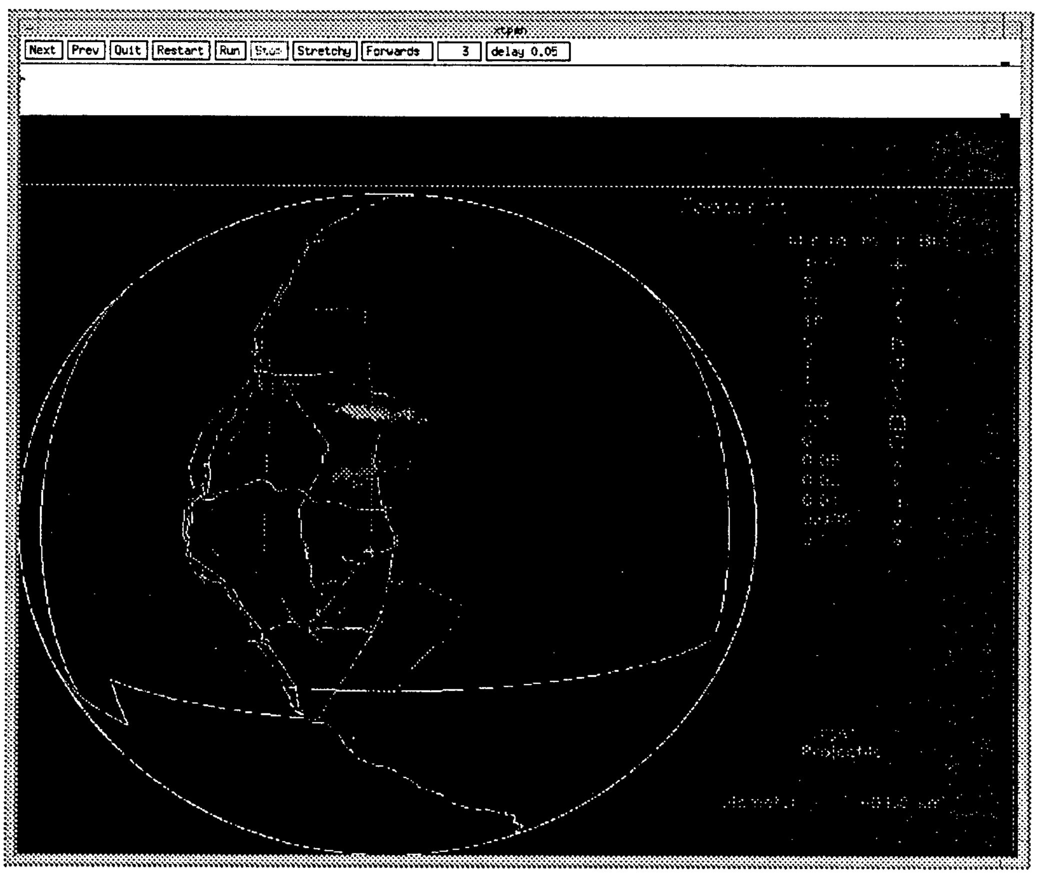


(b)

Figure 2-17. (a) **FOOTPRINT Maps** Window and (b) Resulting **FOOTPRINT Map** (for a Flat Map Display).



(a)



(b)

Figure 2-18. (a) **FOOTPRINT Maps** Window and (b) Resulting **FOOTPRINT Map** (for a Projected Map Display).

Altitude:

Input for the viewpoint altitude in kilometers above the Earth's surface necessary to produce a **Projected** map display. Rays extending from this altitude point to the locus of tangent points on the Earth's surface determine the circular horizon displayed in the fish-eye lens perspective of this map type. This option is disabled if the **Flat** map type is selected. See also the **Type**: specification above. A default value has been established for this value. To enter the default value, select **Default Area** under the **File** menu bar option of the **FOOTPRINT Maps** dialog box window.

Continents:

Input the choice selections for all continental outlines and surface features to be placed in the displayed map. This option is made so that those parts of the world continental outlines not viewed in the map to be displayed can be excluded during map plot processing. This expedites the time it requires to display a map plot. Each continent option acts as an independent toggle switch , so any combination of continents may be selected by clicking on the respective buttons.

Local Maps:

Input the choice selections for all available maps of local or regional interest to the analyst. These will be special maps to assist the particular analyst's requirements. DAW 0.1 currently has only the **WSMR** option which displays the localized detail of the White Sands Missile Range (WSMR) in south-central New Mexico. In addition to continental and political boundaries, the WSMR local map contain details such as major rivers, roads, and the WSMR boundaries. This option may be toggled on or off.

No. of Grid Lines:

Input for the number of grid lines to be displayed in both latitude and longitude in the **Flat** type map display. The grid lines are evenly distributed between the minimum and maximum latitudinal and longitudinal extents of the map. This subdivides the map into evenly spaced grid regions. The latitude and longitude values of the grid lines are shown at the boundaries of the map when it is displayed. This option is disabled if the **Projected** map type is selected.

Display Legend

Controls whether a legend is displayed beside the map plot showing the plot symbols associated with each bin value by which individual fragments are characterized. See the explanation for **Bin Fragments by:** option below.

Bin Fragments by:

Determines the characteristic parameter by which the individual fragments supplied by the IMPACT breakup model are binned. Individual fragments are identified in the footprint map plot by the characteristic parameter bin in which they reside. The fragments can be characterized by one of the four parameter choices given for this option: **Mass**, **Size** (mean diameter), **Kinetic Energy**, or **Ballistic Coefficient**.

Note: *The latter two options are not available if the* **Keplerian** *propagator is used to calculate the fragment trajectory positions (see section 2.6.1).*

Min Bin Values:

Input individual minimum bin boundary values of the characteristic parameter by which individual fragments supplied by the IMPACT breakup model are binned. These bin values represent the *minimum* boundaries so that fragments possessing a certain characteristic parameter of at least the minimum bin boundary value or higher (up to the next higher bin boundary value) are placed in the bin denoted by this bin value. Up to fifteen minimum bin boundary text entry box inputs are provided and are labeled by the descriptors **1:** through **15:**. Default values are provided for the parameters using the IMPACT binning scheme. (Since the fundamental quantity to characterize fragments in IMPACT is mass, the other representations are functional conversions of the mass bin values.) If the bin values are modified, and it is desired to return to the default IMPACT bin values, select the **Default Bins** option under the **File** menu bar option of the **FOOTPRINT Maps** dialog box.

Note: *If the* **Keplerian** *propagator is used (see section 2.6.1), the fragments are already binned by IMPACT into mass (or size) bins, so altering the default binning scheme amounts to binning bins, not individual fragments. This is also true for the fragment mass in the* **Drag Only** *and* **Drag with Winds** *cases using the CHICNLIL model. It is therefore strongly recommended that the bin boundary values not be altered for these cases.*

Protect

Determines whether the current set of minimum bin values selected in the current session are saved when the study as a whole is saved. Normally bin values supplied by IMPACT are used as default values when this dialog box is displayed. Thus, if bin modifications are made and it is desired to save these values for later use, this option *must* be selected. To return to automatic placement of default values when this dialog box is invoked, click this option off.

2.6.2.1 FOOTPRINT Map Window

Each time the **Display Map(s)** menu option is selected in the **File** pull-down menu found in the menu bar of the **FOOTPRINT Maps** dialog box, DAW 0.1 invokes the map processor software package to display a window like that shown in Figures 2-17(b) and 2-18(b). The map processor uses the VPLOT utility of the X-Windows Toolkit to display maps derived from the compressed binary encodings of the vectorized CIA World Data Bank II map database.

A map window will always be entitled **xtpen** (after the VPLOT graphics filter that displays it). The map type, view, and data plotted are determined from the user options set in the **FOOTPRINT Maps** (section 2.6.2) and **FOOTPRINT Propagation** (section 2.6.1) dialog boxes. The map window has the capability to repeatedly cycle the footprint data map displays through all altitudes selected in the **FOOTPRINT Propagation** dialog box. This *automatic cycle mode* has the effect of animating the display if more than one footprint altitude is run. Or the map may be displayed footprint at a time (as determined by altitude) in *single step mode*.

The map display itself shows the map type and viewpoint selected by the user in the **FOOTPRINT Maps** dialog box. When the map is initially displayed, it is centered upon the intercept position of the collision or the breakup position of an explosion event. Visible continental and major political outlines (country and state) are shown along with any details (range boundaries, major roads, and major rivers) provided by the local map database as set by the **Local Maps:** option in the **FOOTPRINT Maps** dialog box. For **Projected** type maps a circular outline encompasses the map, and for **Flat** type maps grid lines labeled in appropriate latitude and longitude values are displayed.

The individual fragment footprint locations are displayed with a symbol corresponding to the particular bin boundary value of the bin in which the fragment resides. The quantity that the bins characterize (mass, size, kinetic energy, or ballistic coefficient) is selected with the **Bin Fragments by:** option located in the **FOOTPRINT Maps** dialog box. The centroid of each symbol indicates the precise footprint position. A legend appears to right of the map indicating the bin value and symbol correspondences. The words Target (in red) and Projectile (in green) also appear in the lower right corner of the display, their color matching the fragment symbols on the map to indicate which debris cloud the fragments belong. A linear scale labeled by a distance value is also displayed to indicate the scale of distances on the map display.

Note: To print a hardcopy of the this map display click **Print** under the **File** item in the menu bar of the **FOOTPRINT Maps** dialog box (section 2.6.2). It cannot be done within this window.

A map window control panel is located at the top of the window (below the title bar). This panel contains ten labeled command buttons which the user may control the display size and the display "animation" cycles. Most simply require clicking on them to activate the action given by the label; however, two act as text entry boxes requiring the user to type a value. Some of the command buttons act as toggle switches. If a button is deactivated or cannot be accessed, its label and button outline are dimmed gray. The command button functions are described below.

Next

Selects the next altitude footprint in the cycle to display if in single step mode (entered by clicking the **Stop** button).

Prev

Selects the previous altitude footprint in the cycle to display if in single step mode (entered by clicking the **Stop** button).

Quit

Exits the current map window, returning control back to the **FOOTPRINT Maps** dialog box.

Restart

Restarts the automatic display cycle from the *beginning* of the sequence (the highest altitude) if the automatic cycle mode had previously been halted using the **Stop** option. This option is deactivated if already running in automatic cycle mode.

Run

Restarts the automatic display cycle from the *next* footprint altitude in the cycle sequence if the automatic cycle mode had previously been halted using the **Stop** option. This option is deactivated if already running in automatic cycle mode.

Stop

Stops the automatic cycle mode allowing single step display of footprint data at each altitude. This option is deactivated if already running in single step mode.

Stretchy

Allows the map display to be stretched in the Y-coordinate direction to fill all of the available window screen. If the window is already filled, clicking on this option does nothing.

Forwards/Backwards

Toggle switch to set the direction of the cycle sequence. To reverse current direction (regardless of direction), click this button.

1, 2, ... (numeric label)

Input the sequence number of the current footprint (determined by altitude) displayed on the map. Sequence numbers are assigned in numerical order from the highest to lowest altitude selected in the **Re-entry Altitude(s):** option of the **FOOTPRINT Propagation** dialog box (section 2.6.1). To select another footprint *while in single step mode* click on this button and type the new sequence number. This input feature is disabled during automatic cycle mode. Whether in the automatic cycle mode or in the single step mode, this label is updated to reflect the sequence number of the current footprint displayed on the map.

delay (numeric value)

Input the time delay in minutes between successive map displays while in automatic cycle mode. Click on this button, then type a new value. Click again or hit **<CR>** to enter the value.

2.7 Collision Dispersion Component Form

Inputs to perform a collision dispersion study are entered through the **COLLISION DISPERSION** component form as shown in Figure 2-19. This form is invoked by selecting the **COLLISION DISPERSION** option under **New Comp** in the **File** menu bar option of the **Study** window. Each selection creates a new **COLLISION DISPERSION** component form with a component number incremented by one over the previously generated form (if one exists).

Refer to section 2.4.1 for a generic description of the DAW model component forms. The options specific to the **COLLISION DISPERSION** form are summarized below. Many inputs required for collision dispersion modeling are identical to those found in the **IMPACT** breakup and **FOOTPRINT** models. Control parameter specifications and event description information are input via windows identical to those invoked from the **IMPACT** model component forms. Propagation model specifications and map functions are specified in windows identical to those invoked from the **FOOTPRINT** component form. The form options are summarized below and a more detailed description of the **Dispersion Inputs** window may be found in section 2.7.1.

Control Parameters...

Clicking on this option invokes the **COLLISION DISPERSION Control Parameters** window where COLLISION DISPERSION model control parameters are entered. These parameters specify general control options for performing the COLLISION DISPERSION model study. The window and its inputs are identical to those found in the **IMPACT Control Parameters** window discussed in section 2.5.1. Refer to section 2.5.1 for a more detailed description of the available options.

The default options are set with the **Velocities** and **Dimensions** choices activated and the **Rotation Rates** item deactivated under the **Individual Fragment Calculations** category. The collision dispersion model *requires* the velocity and dimension data be available for processing the resultant fragment trajectories of the individual fragments. Selection of the rotation rate data is optional.

Event Description...

Clicking on this option invokes the **COLLISION DISPERSION Event Description** window where the breakup event information needed as input to the COLLISION DISPERSION model is entered. The window and its inputs are identical to those found in the **IMPACT Event Description** window discussed in section 2.5.2. Refer to section 2.5.2 for a more detailed description of the options available in this window.

For collision dispersion modeling, the **Explosion** breakup type option is deactivated and cannot be accessed. Similarly, only a **Satellite** vehicle structure type is allowed. The other two types, (**Booster** and **PBV**) are deactivated and cannot be accessed.

Propagation...

Clicking on this option invokes the **COLLISION DISPERSION Propagation** window where the user can select the propagator which determines fragment trajectories from the breakup point. The window and its inputs are identical to those found in the **FOOTPRINT Propagation** window discussed in section 2.6.1. Refer to section 2.6.1 for a more detailed description of the options available in this window.

For collision dispersion modeling, only the **Drag and Winds** propagator option is allowed. The **Keplerian** and **Drag Only** options are deactivated and cannot be accessed. Furthermore, the only allowable re-entry altitude under the **Re-entry Altitudes (m):** input is **0** meters (Earth surface).

Dispersion Inputs...

Clicking on this option invokes the **COLLISION DISPERSION Dispersion Inputs** window where the user can select the statistical dispersions (standard deviation widths) for the important breakup parameters used by the collision dispersion model. Refer to section 2.7.1 for a more detailed description of the options available in this window.

Maps...

Clicking on this option invokes the **COLLISION DISPERSION Maps** window where fragment footprint display conditions can be selected. The map displays of the footprint positions can be invoked from within this window. The window and its inputs are identical to those found in the **FOOTPRINT Maps** window discussed in section 2.6.2. Refer to section 2.6.2 for a more detailed description of the options available in this window.

For collision dispersion modeling, no binning of dispersion data is performed so all options related to this feature are deactivated and cannot be accessed. Specifically, the **Bin Fragments by:**, **Min. Bin Values:**, and **Protect** options are deactivated.

Chapter 3.0 EXAMPLE STUDY TUTORIAL

This chapter presents the steps necessary to perform a *representative* end-to-end study using DAW 0.1. The example study presented here is intended to guide the novice user through the various necessary inputs and dialog box option selections. The study described here is a hypothetical suborbital missile intercept test over the White Sands Missile Range (WSMR). Such a test can produce a significant number of fragments of various sizes and masses that may re-enter and impact over a wide region in the vicinity of the intercept position. This tutorial will cover only the basics. The reader is referred to Chapter 2 for specific details on the available options.

Note: *The figures of dialog box and window screens presented in Chapter 2 directly correspond to the example study explained in this chapter. When noted in the discussions that follow, the reader should refer to these figures.*

Suppose a suborbital missile intercept test is conducted over WSMR and the following intercept information in White Sands Transverse Mercator (WSTM) coordinates is given by:

Intercept Position	Target Velocity	Interceptor Velocity
X = 480000 ft	**V** = 7110.731 ft/sec	**V** = 1507.481 ft/sec
Y = 530000 ft	**Az** = 180°	**Az**= 354.2894°
Z = 344000 ft	**El** = –79.87533°	**El** = 0°

Target:

Mass = 891 kg
80% Aluminum, 15% Steel Alloys, 5% Titanium Alloys
Booster vehicle structure type
One intact component (thrust nozzle), 100% Steel Alloy

Interceptor:

Mass = 79.4 kg
~100% Aluminum
Satellite vehicle structure type
No intact components

The steps necessary to perform the study analyses are discussed in the following sections. The steps in section 3.1 must be done first. The procedures in sections 3.2 - 3.4, which explain the inputs required to operate the models, may be done in any order but they *must* collectively and completely be performed *before* the model components are executed. Section 3.5 explains how to execute the model components. After the components have been run, the results obtained may be examined and analyzed in the form of textual reports, data plots, and map displays. The procedures listed in sections 3.6 - 3.8 explain how to examine this data using the reports processor and graphical features of the DAW 0.1 system. These sections may be performed in any order but *must* be done only *after* the model components providing this data have been executed.

3.1 Starting DAW and Establishing Model Components

To initiate the DAW program and establish the major model components to be used in the study, follow the steps below:

1) In an **xterm** window go to the directory containing DAW 0.1 and type **daw** at the UNIX command line prompt. The dialog box entitled **Debris Analysis Workstation** (Figure 2-1) should appear on the screen.

2) Click the **Study Manager** button. The **Study Manager** dialog box (Figure 2-2) will appear. Any previously saved studies will be listed by name.

3) A *new* study is to be created. To do so, select **New Study** under **File** on the **Study Manager** menu bar. A pop-up dialog box entitled **Study Name Dialogue** will be displayed requesting a new study name. Type the desired name in the entry field provided and click **OK**. For this study, type *wsmrexam*. Doing so brings up the pop-up dialog box entitled **Study** with the name **wsmrexam** (Figure 2-4(a)). Since this is new study, the **Notes:** box and model component section will be blank.

   (*Note*: If a previously saved study is to be loaded, place the mouse pointer on the name box of the desired study and click the *right* mouse button to invoke a miniature menu next to the pointer location. Click on the **Open** item to load the named study.)

3a) *<<Optional>>* If textual notes describing or identifying the study are desired, type the text in the text entry box under the **Notes:** section. This information will be saved if the study is saved. The text may be entered or modified at any time during an interactive DAW session.

4) This study will involve analysis of only one breakup event (the intercept collision). Thus, only a single IMPACT model component is necessary. To generate an IMPACT model component dialog box, select **New Comp** item under **File**. An internal dialog box labeled **IMPACT** with a component number **1** will be placed at the top of the model component section of the **Study** dialog box.

5) Only a *single set* of footprints associated with the collision event shall be displayed for this study. This requires a single FOOTPRINT component module. To generate a FOOTPRINT model component dialog box, select **New Comp** item under **File**. An internal dialog box labeled **FOOTPRINT** with a component number **2** will be placed at the top of the model component section of the **Study** dialog box.

3.2 Setting IMPACT Model Control and Event Description Inputs

Once the last step in section 3.1 has been completed, the **Study** dialog box should appear (Figure 2-4(b)). The control parameters and event description parameters necessary to run the **IMPACT** model component must now be set. The following steps describe how to accomplish this.

1) Click on the **Control Parameters...** option of the **IMPACT** component dialog box. A pop-up dialog box entitled **IMPACT Control Parameters** will appear (Figure 2-6). Initial preset defaults will be assigned to all of the box options.

2) For this study, all three types of individual fragment calculations (velocities, rotation rates, and dimensions) shall be performed. To activate these calculations, click the option button corresponding to each of the three types to highlight them red. For this study, the defaults for the other control parameter options (see Figure 2-6) shall be used. (The latter four options simply define the subset of fragments to consider for the individual fragment calculations. The defaults are sufficient for this example study.)

3) Select **Close** under the **File** menu item to close the **IMPACT Control Parameters** dialog box.

4) Click on the **Event Description...** option of the **IMPACT** component dialog box. A pop-up dialog box entitled **IMPACT Event Description** will appear (Figure 2-7). Initial preset defaults will be assigned to the six parameters related to the energy, mass transfer, and mass fraction descriptions of the breakup process. These defaults will be used in this example. All other *accessible* blank fields (i.e. breakup time, position coordinates, and vehicle coordinates) *must* have values specified by the user, or the program will not operate properly.

5) Since the problem being modeled is a collision event, click the **Collision** option button.

6) Enter the time at which the collision occurs in the six labeled text entry boxes under the **Time:** option.

7) Select the **WS Transverse Mercator** option in the pull-down menu under **Coordinate System:**. This selects the White Sands Transverse Mercator system as the coordinate system in which to accept inputs for the collision event position and vehicle velocities.

8) Input the intercept position coordinates (given earlier in this section) in the appropriate text entry boxes under **Position:**. Input the *target* pre-collision velocity vector components in the appropriate fields for **Velocity:** located immediately below the **Target...** option label. Likewise, input the *interceptor* pre-collision velocity vector components in the appropriate fields for **Velocity:** located immediately below the **Projectile...** option label.

9) For this example, it is assumed that the target is best-described as a *booster* vehicle structure type. To specify this characteristic, click the **Booster** option button next to the **Target...** label. Likewise, the interceptor is assumed to be a **Satellite** vehicle structure type. Click the **Satellite** option button next to the **Projectile...** label.

10) Click on the **Target...** option label to invoke the **IMPACT Target Description** dialog box (Figure 2-8).

11) Click on the **Mass:** text entry box and type in the vehicle mass (891 kg). A value *must* be entered for proper program operation.

12) Since the effects of a liquid fuel mass are ignored in this example study, enter a zero in the **Liquid Fuel Mass:** text entry box. A value *must* be entered for proper program operation.

13) Since only three solid materials are assumed to comprise the target vehicle, only the *first* three option columns under the **Solid Materials:** section need be entered. (The remaining data fields may be left blank.) Enter the assumed mass fractions (0.8, 0.15, and 0.05) in the appropriate text entry boxes next to the **Fractions:** label for the three type of solid materials comprising the target vehicle. Enter the respective material densities (2710, 7600, 4430 kg/m^3) in the appropriate text entry boxes next to the **Densities (kg/m3):** label. Since each of these materials is assumed to represent structural materials, click on the button next to the **Structural:** label corresponding to each of the materials.

14) The target object is assumed to have one intact component made entirely of steel alloy. To input this component, click the **NEW** button to display a row of five blank text entry boxes within the **Intact Components:** box section. Enter the intact component mass in the field under the **Mass** column and the index of the steel alloy material as determined by the column number in the **Solid Materials:** section (in this case two). To allow automatic determination of the intact component dimensions according to the prescribed algorithms contained in the IMPACT model, enter zeroes for the **Length**, **Width**, and **Thickness** fields. (*Note:* The three dimension text entry boxes *must* be supplied a value for proper program operation.)

15) Close the **IMPACT Target Description** window by selecting **Close** under that window's **File** menu item.

16) Returning to the **IMPACT Event Description** dialog window, click on the **Projectile...** option label to invoke the **IMPACT Projectile Description** dialog box (Figure 2-9).

17) Repeat steps 11-13 above, except to input similar information for the interceptor vehicle in the **IMPACT Projectile Description** dialog box. Note that the **Structural:** option and **Intact Components:** section are inaccessible as a result of the vehicle being a *satellite* vehicle structure type, where this information is not used.

18) Close the **IMPACT Projectile Description** window by selecting **Close** under that window's **File** menu item.

19) Upon returning to the **IMPACT Event Description** window, close this window by selecting **Close** under that window's **File** menu item.

3.3 Selecting IMPACT Data Reports

The selection and set-up of desired textual data reports *must* be done *before* running the **IMPACT** component. The steps in this section explain how to do this.

1) Click on the **Reports...** option of the **IMPACT** component dialog box. A pop-up dialog box entitled **IMPACT Reports** will appear (e.g. see Figures 2-10(a), 2-11(a), and 2-12(a)). Initially, the **IMPACT Reports** box will be empty.

2) To set-up a report, select **New Report** under the window's **File** menu item. A **Reports Description** dialog box panel like those shown in Figures 2-10(a), 2-11(a), and 2-12(a) will appear *within* the **IMPACT Reports** window. (*Note*: This panel is not a separate window and, therefore, cannot be manipulated with normal window operations.)

3) Tailor the report format and data to be displayed by selecting the appropriate combination of option switches provided in the **Reports Description** panel. (See section 2.5.3 for a complete discussion of the options available and their possible combinations.) As an example, suppose a general bin data report for the target vehicle is desired which tabularizes the number and cumulative number of fragments, the characteristic and most probable velocities, and the total and cumulative total mass found in each bin. Figure 2-12(b) shows such a report. The **Reports Description** panel switches would need to configured as shown in Figure 2-12(a).

4) Repeat steps 2 and 3 above for *each* output report desired. Every time **New Report** is selected, a new **Reports Description** panel will be placed *beneath* any previously placed panels. If more than one panel is created, a vertical scroll bar appears allowing easy access to any panel not shown on the screen. Each **Reports Description** panel created corresponds to a *separate* report that can be

displayed to the screen. (*Note:* To delete any existing panel, click on the **Reports Description** title label of the panel *to be deleted* with the right mouse button and select **Delete** from the miniature pop-up menu that appears.)

5) Close the **IMPACT Reports** window by selecting **Close** under that window's **File** menu item.

3.4 Setting FOOTPRINT Model Inputs

Certain inputs within the **FOOTPRINT** model component must be entered before the component can be executed. The necessary steps are explained below.

1) Input an integer one (1) in the text entry box of the **Inputs from Study Component #:** option of the **FOOTPRINT** component dialog box. This indicates that this **FOOTPRINT** component is to use the output results from the **IMPACT** component whose component number is labeled as number **1**. (*Note:* This input must be supplied or the FOOTPRINT module will not execute.)

2) Click on the **Propagation...** option of the **FOOTPRINT** component dialog box. A pop-up dialog box entitled **FOOTPRINT Propagation** (Figure 2-16) will appear. Initial default values will be provided for the **Time Step:**, wind model next to the **Drag and Winds** option, and the **Period for Average:** option.

3) The individual fragments generated by the IMPACT model component shall be propagated along their trajectories and influenced by both atmospheric (ballistic) drag and wind drag. To do this, select the **Drag and Winds** option. Use the default White Sands wind model shown in the adjacent pull-down menu. (Note: DAW 0.1 currently incorporates only the White Sands wind model. Thus, there is no choice currently available.)

4) Select **annual** from the pop-up menu under **Period for Average:** as the desired time period over which to average the wind model data.

5) Enter an integer one (1) in the **Wind Speed Sigma:** text entry box to choose a 1-σ variability in determining the wind speed used in the wind drag calculations. This option *must* be supplied for proper program operation.

6) Click the **NEW** button to create new text entry boxes within the boxed area below the **Re-entry Altitudes (m):** option label. Each click on **NEW** creates a single blank text entry box below any previously generated boxes. For this study, five altitudes at which to determine footprint profiles shall be entered. Therefore, click the **NEW** button five times.

7) Enter the desired altitudes (100000, 50000, 20000, 10000, and 0 (ground) meters) in any order in the blank text entry boxes. Figure 2-16 shows four of these visible on the display.

8) Close the **FOOTPRINT Propagation** window by selecting **Close** under that window's **File** menu item.

3.5 Executing Model Components

All inputs and options necessary to execute both the IMPACT and FOOTPRINT component models have now been set as explained in sections 3.1–3.4. Now, the modules must be as executed as explained in the step below. Once a model has been successfully executed, only then can its output ... be examined.

1) To execute the selected model components in sequential order and all at once, select the **Go** option from the **Execute** pull-down menu. If stepwise execution of model components in which components are executed one module at a time is preferred, select **Step** from the **Execute** pull-down menu. Using the **Step** option, the first module encountered whose execution status is either **Not Executed** or **Inconsistent** will be executed. While a module is executing, its status will be labeled **Executing** and will be highlighted by a red field.

3.6 Examining IMPACT Model Textual Reports

After successful execution of the **IMPACT** model component (as indicated by an **Executed** status label), pre-selected data reports can now be examined at the user's convenience. (*Note:* Section 3.3 explains how to pre-select the desired reports before executing the **IMPACT** model component.) To display pre-selected IMPACT textual reports, perform the following steps.

1) Display the **IMPACT Reports** dialog box (e.g. see Figures 2-10(a), 2-11(a), and 2-12(a)) by clicking on the **Reports...** option in the **IMPACT** model component dialog box (Figure 2-5) located in the **Study** window (Figure 2-4(b)). The **IMPACT Reports** dialog box will contain all **Reports Description** dialog box panels pre-selected according to the steps explained in section 3.3.

2) To display a separate pop-up window containing a textual report associated with a **Reports Description** panel, click on the panel's **Reports Description** label in the upper left-hand corner with the right mouse button. Then, select **Browse** from the miniature menu that pops up near the mouse pointer. Figures 2-10(b), 2-11(b), and 2-12(b) show the example study results for the target vehicle as selected by the corresponding **Reports Description** panels shown in Figures 2-10(a), 2-11(a), and 2-12(a), respectively. (*Note:* Multiple report windows may be displayed on the screen at one time. The report window title will be the pathname of the output file being displayed.)

3) To print a hardcopy of the information displayed within a reports window on an attached printer, select **Print** under that window's **File** menu item.

4) To close a report window, select **Close** under that window's **File** menu item.

3.7 Examining IMPACT Model Data Plots

After successful execution of the **IMPACT** model component (as indicated by an **Executed** status label), line and scatter plots of a wide variety of data produced by IMPACT can now be examined at the user's convenience. To display plots of IMPACT model results, perform the following steps.

1) Display the **IMPACT Plot Selection** dialog box (Figure 2-13) by clicking on the **Plots...** option in the **IMPACT** model component dialog box (Figure 2-5) located in the **Study** window (Figure 2-4(b)).

2) Select the vehicle to display data on **(Target** or **Projectile)** by clicking the desired option command button.

3) Select the desired plot to display from the list of plot options presented in the **IMPACT Plot Selection** dialog box by clicking on the command button next to the plot choice. After a brief delay, an ACE/gr (Ref. 3) pop-up window containing the selected plot is displayed (e.g. Figure 2-14). (*Note:* Multiple plot windows may be displayed on the screen at one time.)

4) To print a hardcopy of the plot displayed within a plot window on an attached printer, select **Print** under that window's **File** menu item.

5) To close a plot window, click on the command button labeled **Exit** on the ACE/gr command panel located to the left of the plot.

6) To rescale axes, relabel plot and axes titles, pan or zoom in/out, or to perform a myriad of other functions capable of modifying the displayed plot, select the proper command button on the ACE/gr command panel located to the left of the plot or the appropriate dialog box listed under the **File**, **Edit**, or **View** menu bar options. The reader is referred to Reference 3 for more information about the many ACE/gr options available in this window.

3.8 Examining FOOTPRINT Model Map Plots

After successful execution of the **FOOTPRINT** model component (as indicated by an **Executed** status label), displays line and scatter plots of a wide variety of data produced by IMPACT can now be examined at the user's convenience. To display plots of IMPACT model results, perform the following steps.

1) Display the **FOOTPRINT Maps** dialog box (e.g. Figures 2-17(a) and 2-17(b)) by clicking on the **Maps...** option in the **IMPACT** model component dialog box (Figure 2-15) located in the **Study** window (Figure 2-4(b)).

2) Select the type of map to display **(Projected** or **Flat)** by clicking the desired option command button under the **Type:** option. Figure 2-17(b) demonstrates the **Flat** map type for an example study debris footprint at 20000 m (as indicated by cycle number 3 in the map menu) where fragments are binned by mass. Figure 2-18(b) shows **Projected** map type for the example study debris footprint also at 20000 m except that the fragments are binned according to ballistic coefficient.

3) Enter the viewpoint center latitude and longitude geodetic coordinates for the map display in the appropriately labeled text entry boxes under the **Center:** option. For the WSMR example study, a latitude of 33° N and -106° W (or 256° E) will center the map near the east-central boundary of WSMR, very close to the location of the intercept point and footprint positions. (*Note:* Longitude can be expressed either *east of Greenwich*, where it will be positively-valued, or *west of Greenwich* where it will be negatively-valued.)

4) If the map type is **Flat**, enter the angular viewing extent ($\Delta\theta$) about the viewpoint center in both latitude and longitude in the text entry box labeled **Delta:**. The map, then, will be displayed with an angular range twice this value. Figure 2-17(b) shows a flat map with a 2° $\Delta\theta$ value giving an overall 4° viewing range. (For this map type, the **Altitude:** specification is inaccessible.)

   If the map type is **Projected**, enter a viewpoint altitude in kilometers above the Earth's surface. A fish-eye lens view will be displayed with the map boundaries corresponding to the locus of tangent points to the surface extending from the viewpoint. Figure 2-18(b) shows a projected map with a 5 km viewpoint altitude.

5) Select the continents to be *considered* from the map database *in constructing the map display* by clicking the desired command buttons. For the WSMR study, it is recommended that both **N. America** and **S. America** be selected. (*Note:* Features and outlines of Mexico are included in the **S. America** database.)

6) Activate display of WSMR-specific features on the map by clicking on the **WSMR** command button under the **Local Maps:** option.

7) For the **Flat** map type, enter the desired number of grid lines to subdivide the angular viewing range in both latitude and longitude. Entering a value of three, for example, causes three grid lines in both latitude and longitude to be displayed, subdividing the angular range into four regions (as is done in the display of Figure 2-17(b)). Each grid line will be labeled in geodetic coordinates unless the WSMR local map is selected, in which case the grid lines are labeled in WSTM coordinates.

8) Click on the **Display Legend** command button to activate display of the legend in the map display.

9) Click on the desired parameter (**Mass, Size, Kinetic Energy**, or **Ballistic Coefficient**) by which to characterize (i.e. bin) the individual fragment data displayed in the debris footprints. As examples, Figure 2-17(b) shows the example study data binned by mass according to the default IMPACT mass bins and Figure 2-18(b) shows the same data binned by ballistic coefficient over fifteen bins whose minimum bin boundaries are defaults determined by the IMPACT model.

10) If desired, enter new bin boundaries to consider for *displaying* the individual fragments generated by the IMPACT model. Normally, it is not necessary to alter the default values provided unless it is desired to show *only a subset of the fragments on the map display.* Figure 2-17(b) shows the map display for the default minimum mass bin boundary values of the example study data and Figure 2-18(b) shows the corresponding map display for the default minimum ballistic coefficient bin boundary values.

Chapter 4.0 SUPPLEMENTAL INFORMATION

The DAW 0.1 system embodies the IMPACT 4.0 breakup model and FOOTPRINT fragment impact pattern model that have been thoroughly documented in References 1 and 2. The interested user should refer to this documentation to inquire about specific details of the models not covered in this manual. DAW Version 0.1, however, includes a few model modifications and additions designed to make the IMPACT/FOOTPRINT model combination better suited for performing missile intercept test and range-safety analyses by the U.S. Army White Sands Missile Range (WSMR) for support of the THAAD Program. These modifications and additions are not documented elsewhere, so for the sake of completeness, they are briefly described in this chapter.

4.1 Coordinate Systems

DAW 0.1 allows input of breakup position and vehicle velocities in five distinct coordinate systems. The software, however, performs all *internal* calculations in an astronomical Earth Centered Inertial (ECI) reference frame using meters, seconds, and radians as units. This requires that non-ECI coordinate systems input by the user be transformed to the internal ECI coordinates and then back again in the user-selected coordinate system as needed for presentation or display purposes (i.e., in interactive dialog box entries and graphical map or plot displays). Furthermore, if inputs are made in one system and then the user selects another system, transformations are automatically made to reflect the proper new system values. Other coordinate systems provided include *geodetic*, *White Sands Transverse Mercator*, and *White Sands Cartesian* coordinate systems. These coordinate systems are explained below.

Earth Centered Inertial Coordinate System

The Earth centered inertial coordinate system is an inertial orthogonal system whose origin is located at the Earth's center. Positions are defined by the coordinate set (X, Y, Z). Lengths in this system are defined in units of meters. The positive X-axis points toward the point of Aries at vernal equinox. The Z-axis is aligned with Earth's rotational axis and is defined positive North.

Geodetic Coordinate System

In the geodetic coordinate system, positions are defined by the coordinate set (geodetic latitude, longitude, and altitude). In this system, latitude is defined as positive North from the equator and is specified in degree and minutes. This latitude is the geodetic latitude defined as the angle between the equatorial plane and the normal to the surface of the slightly oblate geoid. Longitude is defined as positive East from Greenwich and is specified in degrees and minutes. Altitude is defined as the height above the Earth spheroid (geoid) and is specified in feet. This is a commonly used system for referencing data for external distribution because of its generality.

Geographic Coordinate System

In the geographic (or geocentric) coordinate system, positions are defined by the coordinate set (geographic latitude, longitude, and altitude). In this system, latitude is defined as positive North from the equator and is specified in degree and minutes. This latitude is the geocentric latitude defined as the angle between the equatorial plane and the radius from the geocenter. Longitude is defined as positive East from Greenwich and is specified in degrees and minutes. Altitude is defined as the height above the Earth spheroid (geoid) and is specified in feet. This is a commonly used system for referencing data for external distribution because of its generality.

White Sands Transverse MercatorCoordinate System

In the White Sands Transverse Mercator (WSTM) coordinate system (Ref. 4) positions are represented by the coordinate pair (Easting, Northing). Easting is defined as the number of feet East from the WSTM origin. This origin is artificially biased to (500,000 ft, 100,000 ft). This allows all range locations to be specified as pairs of positive numbers. Northing is defined as the number of feet North from the WSTM origin. Although the software allows the specification of altitude (in feet, positive up from the Earth spheroid as in the geodetic system), altitude is not used in this coordinate system. The WSTM coordinate system is designed to work on an angular division of the Earth's surface. The resulting shape looks like the peel of an orange quarter that has been flattened. The angular division is approximately 3 degrees to the east and west of the central meridian. This central meridian bisects the WSMR from North to South. The origin of the coordinate system is placed to the South and West at the southwest corner of the range. Based on conversations with WSMR personnel who developed this transformation, the system is not particularly accurate at long distances from WSMR. Although there are no mathematical discontinuities in the coordinate transformation equations, the accuracy of these equations is in questions beyond approximately 2 degrees in longitude from the central meridian and 15 degrees in latitude from the origin.

White Sands Cartesian System

The White Sands Cartesian System (WSCS) is a plane tangent to the surface of the earth at the WSMR origin (Ref. 4). In this system the positions are defined by the coordinate set (Easting, Northing, altitude). Easting is defined as the number of feet to the East of the WSMR origin. Northing is defined as the number of feet to the North of the WSMR origin. Altitude is defined as the number of feet above the plane. The WSCS origin is artificially biased to {500,000 ft, 500,000 ft, 0 ft}. This allows all positions on WSMR to be represented with positive numbers. It should be noted that it is entirely possible to have a positive distance above the Earth spheroid and a negative WSCS altitude. In addition, if this coordinate system is used over extended distances, the curvature of the earth tends to produce non-intuitive and difficult to use results. There are no mathematical discontinuities in the coordinate transformation equations.

The WSTM, WSCS, and geodetic coordinate system conversions have been validated against existing validated WSMR software. Geodetic, geographic, and ECI conversions utilize existing, validated Aerospace Corporation software. The conversion link between the two coordinate system groups occurs through the *geodetic* system. Validation tests were conducted to determine conversion errors. The maximum errors in a single conversion amounted to approximately ± 5 feet in distance dimension and ± 0.01° in angular dimension. The expected sources of these errors are the differences in the computational hardware (IBM PC vs. Sun Workstation) and software (FORTRAN vs. C) used in the validation studies.

4.2 Debris Re-entry Propagator (CHICNLIL Model)

The debris re-entry propagator model (CHICNLIL) developed by Aerospace Corporation has replaced the drag-inclusive propagator previously incorporated into the FOOTPRINT model. This updated model is intended to conduct studies specific to the U.S. Army WSMR THAAD Program. CHICNLIL is a fast-running debris re-entry propagator which incorporates the effects of atmospheric and winds drag. This model and the associated WSMR wind database has been fully integrated into the framework of DAW requiring only that the user specify several run condition parameters in the **FOOTPRINT Propagation** dialog box (see section 2.5.1). CHICNLIL itself is a self-contained module, and the input and output interfaces of this module have been made transparent to the DAW analyst.

Inputs

CHICNLIL requires as external inputs the following parameters:

- *Final altitude of interest for the integration* (e.g., either the altitude of the impact site or the altitude of air traffic concern). One or more altitudes may be entered under the **Re-entry Altitudes (m):** option of the **FOOTPRINT Propagation** dialog box. Each altitude entered constitutes a separate run of CHICNLIL.

- *Wind data file to use.* Currently, DAW 0.1 supports only the White Sands wind data. When other data files become available, the data file will be selected in the pull-down menu of the **Drag and Winds** option in the **FOOTPRINT Propagation** dialog box.

- *Time period over which to average the wind speed data.* This parameter may be specified annually, seasonally, or monthly. If annually, the data is averaged over twelve months of a year. If seasonally, the data is averaged over three months of the season specified. If monthly, the data is averaged over the single month specified. The choice is entered in the pull-down menu of the **Period for Average:** option in the **FOOTPRINT Propagation** dialog box.

- *Wind speed standard deviation (σ) value to use.* This specifies the statistical variation from the average wind speed of a given time period allowed in the wind drag calculations. It is entered in the **FOOTPRINT Propagation** dialog box under the **Wind Speed Sigma:** option where integer multiples of σ may be entered.

- *Initial earth centered inertial (ECI) state vectors of the target or projectile debris.* This includes the breakup position starting point coordinates (**X**, **Y**, **Z**) and the initial net velocity vector coordinates ($\mathbf{V_x}$, $\mathbf{V_y}$, $\mathbf{V_z}$)of each debris fragment to be propagated. This information is supplied by the IMPACT component model and not as interactive input by the user. CHICNLIL also uses the epoch, and the size, mass, and apogee/perigee of each fragment from the IMPACT output.

Winds Data

The winds data files (Ref. 5) provided include yearly data, seasonal data, and monthly data. The data is in the format: wind direction angle (deg), mean wind speed (knots), one-sigma wind speed addition factor (knots), maximum altitude of wind information validity (feet a.m.s.l.). The wind direction angle represents the direction *from* which the wind is blowing. For example, the winds data input file for August is shown below:

```
126,5,6,5000
143,9,10,10000
73,11,12,15000
79,12,13,20000
329,13,15,25000
292,17,19,30000
291,21,23,35000
295,24,26,40000
303,22,24,45000
326,16,18,50000
82,11,11,55000
89,13,9,60000
```

92,18,7,65000
91,22,7,70000
91,27,7,75000
91,30,7,80000
91,32,8,85000
91,35,9,90000
91,37,10,95000
90,39,10,100000

Atmospheric Density Profile

The atmospheric density model used in this program is the average annual data as taken from a reference atmosphere specific to the WSMR vicinity (Ref. 5). The program assumes that the effective atmosphere extends from mean sea level up to 72 km (a.m.s.l.).

Integrator

CHICNLIL uses a simple Euler Integrator with a fixed 1.0 second time step. At each time step, the motion of the projectile is assumed to be affected by a uniform acceleration. That acceleration is comprised of the gravitational and drag (ballistic and, if specified, wind) accelerations. The resultant state vector is then sent through the iteration again until the final altitude is achieved.

Outputs

The outputs produced by CHICNLIL are utilized by the FOOTPRINT processor to produce the map displays of the re-entry footprint data. The following data are provided for each fragment at each user-specified re-entry altitude (after propagation achieves this final altitude):

- Geodetic latitude (deg) position of the fragment at the re-entry or impact altitude
- Longitude (deg) position of the fragment at the re-entry or impact altitude
- Mass (kg) of the fragment
- Area (m^2) of the fragment
- Kinetic energy (J) of the fragment
- Time (sec) after breakup
- Final altitude (km) reached

These CHICNLIL outputs are then used by the FOOTPRINT map processor to graphically display the data on screen maps.

4.3 IMPACT 3.0 to IMPACT 4.0 Modification

The major upgrade from IMPACT 3.0 to IMPACT 4.0 is the implementation of the option to perform automatic determination of energy partitioning in *collision* events. In the **Event Description** dialog box (section 2.4.2), if a **Collision** type event is selected and the user inputs both a *zero* value for the **Energy Fraction to Heat, Light, and Fragmentation:** option and a *zero* value for the **Energy Fraction to**

Debris Spreading: option, the program will *automatically* determine the actual energy partitioning to be done.

The algorithm for automatic determination of the collisional energy partitioning was developed using theory and data from hydrocode hypervelocity impact runs presented in Reference 6. According to this reference, as the kinetic energy per target mass decreases, the total fraction of energy "lost" to heat, light, and spreading increases until it reaches one. At that point there is a completely inelastic collision between the target and the projectile.

4.4 Collision Dispersion Model

A collision dispersion model has been developed and incorporated into the DAW 0.1 system. This model provides a mechanism for evaluating the effects of perturbations on the size, shape, and location of the debris footprint. It is intended to be a fast-running first-order analysis tool capable of calculating fragment footprint ellipsoids based on the dispersion of fragments within probability of containment boundaries. Dispersions about a nominal collision scenario, based on prior parameter sensitivity studies, are used to determine an impact ellipse on the ground. The *scenario parameters* are defined as the breakup position coordinates (X, Y, Z), the pre-collision velocity coordinates (at the breakup position) of both the target (V_{tx}, V_{ty}, V_{tz}) and interceptor projectile (V_{ix}, V_{iy}, V_{iz}). The *fragment parameters* are those estimated by the IMPACT breakup model and include individual fragment mass, surface area, and perturbed velocity magnitude and direction. The impact dispersion ellipse is defined by the center point latitude and longitude, semimajor axis, and semiminor axis.

The collision dispersion model methodology is described in the steps listed below.

1) Define (input) the *nominal scenario parameters* for the collision breakup event. The nominal case defines the conditions about which the parameters shall be dispersed. The following nominal parameters are required by the model:

   - Impact (breakup) position

     -- altitude, H
     -- latitude, θ_{bu}
     -- longitude, φ_{bu}

   - *Target* vehicle velocity

     -- magnitude (speed), V_t
     -- azimuth angle (relative to local North), A_t
     -- elevation angle (relative to the local horizontal frame at the impact position), E_t

   - *Interceptor* vehicle velocity

     -- magnitude (speed), V_i
     -- azimuth angle (relative to local North), A_i
     -- elevation angle (relative to the local horizontal frame at the impact position), E_i

2) Define (input) the *scenario parameter dispersions* about the nominal values. The dispersions are obtained from preliminary sensitivity studies of the parameters. The following parameters are required by the model:

- Impact (breakup) position

  -- altitude dispersion, ΔH
  -- latitude dispersion, $\Delta \theta_{bu}$
  -- longitude dispersion, $\Delta \varphi_{bu}$

- *Target* vehicle velocity

  -- magnitude (speed), ΔV_t
  -- azimuth angle (relative to local North), ΔA_t
  -- elevation angle (relative to the local horizontal frame at the impact position), ΔE_t

- *Interceptor* vehicle velocity

  -- magnitude (speed), ΔV_i
  -- azimuth angle (relative to local North), ΔA_i
  -- elevation angle (relative to the local horizontal frame at the impact position), ΔE_i

3) Define (input) the *fragment parameter dispersions* as predicted by the IMPACT breakup model. These dispersions are obtained from preliminary sensitivity studies of the parameters. The following parameters are required by the model:

- *Target* fragment

  -- mass dispersion, ΔM_{ft}
  -- surface area dispersion, ΔSA_{ft}
  -- velocity magnitude (speed) dispersion, ΔV_{ft}

- *Interceptor* fragment

  -- mass dispersion, ΔM_{fi}
  -- surface area dispersion, ΔSA_{fi}
  -- velocity magnitude (speed) dispersion, ΔV_{fi}

4) Generate the *nominal impact footprint*. The footprint data includes both nominal fragment data derived from the IMPACT 4.0 model and nominal impact ellipse parameters on the ground are calculated from the average impact distribution of individual debris impact positions. The following data are calculated:

- Nominal *target* fragment

  -- mass, M_{ft}
  -- surface area, SA_{ft}
  -- velocity magnitude (speed), V_{ft}

- Nominal *interceptor* fragment

  -- mass, M_{fi}
  -- surface area, SA_{fi}

- velocity magnitude (speed), V_{fi}

- Nominal impact ellipse parameters

  - center latitude, θ_{en}
  - center longitude, φ_{en}
  - semimajor axis, a_{en}
  - semiminor axis, b_{en}

5) Determine the fragment data and impact ellipse parameters corresponding to the maximum and minimum values of each *scenario parameter.*

6) Determine the maximum, average, and minimum values of each *fragment parameter* based on the data from the *scenario parameter* sensitivity study (calculated in step 5 above).

7) Determine the impact ellipse parameters corresponding to the maximum, average, and minimum *fragment parameter* values (calculated in step 6 above).

8) Compute the *impact ellipse parameter* first and second order estimators corresponding to each of the *scenario parameter* perturbations (calculated in step 5 above).

9) Compute the *fragment parameter* first and second order estimators corresponding to each of the *scenario parameter* perturbations (calculated in step 5 above).

10) Compute the *fragment parameter* first and second order estimators corresponding to each of the *fragment parameter* perturbations (calculated in step 6 above).

11) Determine the matrix of impact ellipse center of mass maximum latitude and longitude errors for each *scenario and fragment parameter.*

12) Determine the variance of the semimajor and semiminor axis lengths.

13) Compute the χ^2 parameter corresponding to the user-specified probability of interest.

14) Compute the latitude, longitude, semimajor axis, and semiminor axis dispersions corresponding to the computed χ^2 parameter (calculated in step 13 above).

REFERENCES

1. Sorge, M. E. and Johnson, C.G., "Space Debris Hazard Software: Program IMPACT Version 3.0 User's Guide," The Aerospace Corporation, Report No. TOR-93(3076)-3, El Segundo, CA, August 1993.

2. Sorge, M. E., "Space Debris Hazard Software: Program IMPACT Version 2.0 Breakup Model," The Aerospace Corporation, Report No. TOR-92(2076)-2, El Segundo, CA, April 1992.

3. Turner, P.J., "ACE/gr User's Manual - Graphics for Exploratory Data Analysis," Software Documentation Series, SDS3, 91-3, Center for Coastal and Land-Margin Research, Oregon Graduate Institute of Science and Technology, 1992.

4. Corson, J. H., "Coordinate Systems Related to WSMR," Data Reduction Technical Report, Data Reduction Division, White Sands Missile Range, July 1964.

5. "Range Reference Atmosphere 0-70 km," U.S. Army White Sands Missile Range Document Number 365-83, August 1983.

6. Kinslow, R., *High-Velocity Impact Phenomena*, Academic Press, 1970.

Appendix

Introduction

The White Sands Missile Range (WSMR) intends to perform several intercept tests as part of an effort with the Theater High Altitude Air Defense (THAAD) program office. These intercept tests have the potential to create hazardous debris clouds. It is the responsibility of the WSMR Safety Office to ensure that safety is not compromised by these tests. The Aerospace Corporation was requested to provide assistance in the debris generation modeling and to provide guidance in the determination of the appropriate estimated debris ground footprint.

During several of the meetings, the standard proposal for determining the debris ground footprint was to perform a Monte Carlo analysis for the intercept. Run lengths of between 10,000 and 1,000,000 cases were estimated for this analysis. For each case, a debris cloud would be generated, all of the fragment characteristics transferred to a trajectory simulation program, and then each fragment would be individually propagated to the ground in the presence of an atmosphere, gravity, and winds. This task was expected to require several days of computer time to complete execution. With enough iterations, it is certainly possible to create a well defined shape representing where the debris lands. Several problems exist with this approach. First, although there is a well defined footprint, there is no indication of the probability of containment. Second, if the containment boundary for a specific probability is desired, it will be extremely difficult to extract from this data. Third, the execution of this execution will take a long time (several days). This leads to reluctance to perform the analysis any more than is absolutely necessary. This approach does have several advantages. First, it is not necessary to make any assumptions about the statistical distributions of the inputs or processes. Second, parameter correlations are handled directly.

Another approach to the containment boundary computation is a covariance analysis. For the WSMR problem, as currently defined, this would require the execution of between 25 and 2500 cases. For each case a debris cloud would be generated, all of the fragment characteristics transferred to a trajectory program, and then each fragment would be individually propagated to the ground in the presence of an atmosphere, gravity, and winds. It should be noted that the only significant difference to this point with respect to the Monte Carlo method, is the number of cases to be executed. The next step is to compute most likely footprints for each case. The most likely footprint parameters (center latitude, center longitude, semimajor axis, semiminor axis) are used to compute the state vector and wind covariance matrices. Computational separation, and later summing, of the two covariance matrices is legitimate because the wind and state vector errors are independent. The total covariance matrix (the sum of the state vector and wind covariance matrices) is used to compute the debris containment footprint boundary. Two simplifying assumptions are made for the analysis. First, the dispersion errors are Gaussian, and second, the dispersion errors are uncorrelated. Neither of these assumptions is perfectly met. However, given the debris generation model accuracy, they seem reasonable as approximations.

WSMR decided that it would like an opportunity to evaluate the feasibility of a covariance analysis technique. There were five ground rules imposed on the development effort. First, no more than four labor weeks were to be used to develop, implement, and test the tool. Second, initially only collisions were to be considered. Third, initially only ground footprints were to be computed. Fourth, simplifications should result in more conservative results. Fifth, computational accuracy should be appropriate for the accuracy of the debris generation model. With these ground rules, a simplified analysis code was put together. Testing has been limited to verify that the code executes and the results *look* reasonable. The following section describes the proposed methodology (in detail) and contrasts this methodology with the code as written.

Methodology

A nominal event scenario is defined and the perturbations of interest defined. Two event scenarios are possible: a two body collision, and a single body explosion. A different set of perturbations is relevant for each of these scenarios. Debris clouds are generated for the nominal and perturbed cases. Currently available debris generation tools use empirical models to statistically generate the debris fragments and the fragment characteristics. It is necessary to mitigate this statistical variation by generating several debris clouds for each case. The number of debris clouds necessary for this mitigation should be between 10 and 100. Scenarios which generate large numbers of fragments require fewer debris clouds. These large numbers of fragments already provide good statistical distribution of velocity vectors and fragment characteristics. Scenarios with small numbers of fragments have less variation per cloud, and therefore require more debris clouds. For each case, the cloud to cloud debris fragment characteristic means and variance are computed. If the variances are too large, consideration should be given to increasing the number of debris clouds generated for each case.

Each of the scenario perturbations should have at least two perturbation values (one to either side of the nominal value). Additional values for the perturbed variables present an improved understanding of the scenario debris sensitivity to variation in the perturbed variable. These additional perturbation values also significantly increase the require execution time of the analysis. Two (or more) perturbation cases plus the nominal case permit the determination of the linearity of the characteristic sensitivity. Significant characteristic nonlinearity is a warning that further analysis is required.

Each debris cloud is propagated to impact. At impact, the position of each fragment is designated by the triplet (latitude, longitude, altitude). All of the fragment altitudes will be identical to the impact altitude. Impact coordinates are then converted to Earth Centered Relative coordinates (x, y, z). In this coordinate system, the x axis is from the center of the Earth through the Greenwich meridian, the z axis is from the center of the Earth through the North pole, and the y axis is selected to form a right handed, cartesian system. The origin of this coordinate system is the center of the Earth. To begin the coordinate conversion, it is necessary to compute the radial distance from the center of the Earth to each of the impact points. The following equations perform the necessary computations.

$$f = \frac{R_e - R_p}{R_e}$$
$$P = 2f - f^2$$
$$D = \sqrt{1 - P \sin^2 \phi_D}$$
$$\varepsilon = P\left(\frac{R_e}{D}\right)\left(\frac{\sin\phi_D \cos\phi_D}{DR_e + h}\right)$$
$$\phi_C = \phi_D - \tan^{-1} \varepsilon$$
$$r = \left(DR_e + h\right)\sqrt{1 + \varepsilon^2}$$

Where

h	altitude of the fragment impact point
r	radial distance of the fragment impact point from the center of the Earth
R_e	equatorial radius of the Earth
R_p	polar radius of the Earth
ϕ_C	geocentric latitude of the fragment impact point.

ϕ_D geodetic latitude of the fragment impact point.

Three dimensional polar coordinate transformation to cartesian coordinates is implemented with:

$$x = r\cos\phi_C \cos\lambda$$
$$y = r\cos\phi_C \sin\lambda$$
$$z = r\sin\phi_C$$

Where

- x ECR x axis value
- y ECR y axis value
- z ECR z axis value
- ϕ_C geocentric latitude of the fragment impact point
- λ longitude of the fragment impact point.

For each of the cases (nominal and perturbed) an average impact footprint is computed. For each cloud (in a case), the fragment impact ECR coordinates are vector summed and divided by the number of clouds (in the case) to compute the footprint center.

$$x_{c_{i,J}} = \frac{\sum_{j=1}^{n_{i,J}} x_{i,j,k}}{n_{i,j}}$$

$$y_{c_{i,J}} = \frac{\sum_{j=1}^{n_{i,J}} y_{i,j,k}}{n_{i,j}}$$

$$z_{c_{i,J}} = \frac{\sum_{j=1}^{n_{i,J}} z_{i,j,k}}{n_{i,j}}$$

Where

- $n_{i,j}$ number of fragments in the jth cloud of the ith case
- $x_{i,j,k}$ x axis value for the kth fragment of the jth cloud for the ith case
- $x_{c_{i,J}}$ x axis value for the average footprint center for the jth cloud of the ith case
- $y_{i,j,k}$ y axis value for the kth fragment of the jth cloud for the ith case
- $y_{c_{i,J}}$ y axis value for the average footprint center for the jth cloud of the ith case
- $z_{i,j,k}$ z axis value for the kth fragment of the jth cloud for the ith case
- $z_{c_{i,J}}$ z axis value for the average footprint center for the jth cloud of the ith case.

The radial distance of each of the fragment impact points from this cloud average center is then computed using:

$$d_{i,j,k} = \sqrt{\left(x_{i,j,k} - x_{c_{i,J}}\right)^2 + \left(y_{i,j,k} - y_{c_{i,J}}\right)^2 + \left(z_{i,j,k} - z_{c_{i,J}}\right)^2}\ .$$

Where

$d_{i,j,k}$ distance of the kth fragment of the jth cloud for the ith case form the center of the jth cloud for the ith case.

The fragment with the largest radial distance is assumed to lie at the semimajor axis and the corresponding radial distance is assumed to be the semimajor axis length. Now compute the perpendicular distance from the semimajor axis for every fragment impact point using:

$$\overline{v}_{i,j,k} = \begin{pmatrix} x_{i,j,k} - x_{c_{i,J}} \\ y_{i,j,k} - y_{c_{i,J}} \\ z_{i,j,k} - z_{c_{i,J}} \end{pmatrix}$$

$$\overline{v}_{sm_{i,J}} = \begin{pmatrix} x_{sm_{i,J}} - x_{c_{i,J}} \\ y_{sm_{i,J}} - y_{c_{i,J}} \\ z_{sm_{i,J}} - z_{c_{i,J}} \end{pmatrix}$$

$$\alpha_{i,j,k} = \cos^{-1}\left(\frac{\overline{v}_{i,j,k} \bullet \overline{v}_{sm_{i,J}}}{\left\|\overline{v}_{i,j,k}\right\|\left\|\overline{v}_{sm_{i,J}}\right\|}\right)$$

$$p_{i,j,k} = \left\|\overline{v}_{i,j,k}\right\|\cos\alpha_{i,j,k}$$

Where

$p_{i,j,k}$ perpendicular distance of the kth point from the semimajor axis for the jth cloud and the ith case

$\overline{v}_{i,j,k}$ vector from the jth cloud footprint center to the kth point for the ith case

$\overline{v}_{sm_{i,J}}$ vector from the jth cloud footprint center to the semimajor axis point for the ith case

$\alpha_{i,j,k}$ angle between the vectors from the footprint center of the jth cloud and the kth point and the semimajor axis points, respectively (for the ith case).

The point with the largest perpendicular distance to the semimajor axis is assumed to lie on the semiminor axis. The corresponding perpendicular distance is the semiminor axis length.

The footprint center, semimajor axis length and the semiminor axis length are averaged over the set of footprints resulting from the propagation of all the clouds for a given case. Equations for this computation are:

$$x_{c_i} = \frac{\sum_i x_{c_{i,J}}}{n_i}$$

$$y_{c_i} = \frac{\sum_i y_{c_{i,J}}}{n_i}$$

$$z_{c_i} = \frac{\sum_i z_{c_{i,J}}}{n_i}$$

Where:

n_i	number of clouds in the i^{th} case
x_{c_i}	x axis value for the center of the average cloud for the i^{th} case
y_{c_i}	y axis value for the center of the average cloud for the i^{th} case
z_{c_i}	z axis value for the center of the average cloud for the i^{th} case.

At this stage of the analysis, there is a footprint center, semimajor axis length, and semiminor axis length for the nominal and each perturbed case. Assuming a flat Earth (reasonable for the footprint sizes expected), the footprint centers can be simplified from three coordinates (ECR) to two coordinates (lat, lon) with an implicit altitude. The necessary computations are:

$$r_i = \sqrt{x_{c_i}^2 + y_{c_i}^2 + z_{c_i}^2}$$
$$\lambda_i = \tan^{-1}\left(\frac{y_{c_i}}{x_{c_i}}\right)$$
$$\phi_{C_i} = \sin^{-1}\left(\frac{z_{c_i}}{r_i}\right)$$
$$f = \frac{R_e - R_p}{R_e}$$
$$P = 2f - f^2$$
$$D_i^* = \sqrt{1 - P\cos^2\phi_{C_i}}$$
$$\varepsilon_i = 0$$
$$\phi_{D_i} = \phi_{C_i}$$
$$D_i = \sqrt{1 - P\cos^2\phi_{D_i}}$$
$$h_i = \frac{r_i}{\sqrt{1+\varepsilon^2}} - D_i R_e$$
$$\varepsilon_i = P\left(\frac{R_e}{D_i^*}\right)\frac{\sin\phi_{C_i}\cos\phi_{C_i}}{D_i^* R_e + h_i\left(\frac{D_i}{D_i^*}\right)}$$
$$\phi_{D_i} = \phi_{C_i}$$
$$D_i = \sqrt{1 - P\cos^2\phi_{D_i}}$$
$$h_i = \frac{r_i}{\sqrt{1+\varepsilon^2}} - D_i R_e$$
$$\varepsilon_i = P\left(\frac{R_e}{D_i^*}\right)\frac{\sin\phi_{C_i}\cos\phi_{C_i}}{D_i^* R_e + h_i\left(\frac{D_i}{D_i^*}\right)}$$
$$\phi_{D_i} = \phi_{C_i}$$

This procedure produces worst errors of order 10^{-12} degrees in latitude and 10^{-6} feet in altitude. The four tuples

$$\left(\phi_{D_i}, \lambda_i, a_i, b_i\right)$$

Where

ϕ_{D_i}	is the geodetic latitude of the footprint center for the i[th] case
λ_i	is the longitude of the footprint center for the i[th] case
a_i	is the semimajor axis for the i[th] case
b_i	is the semiminor axis for the i[th] case

are formed. Each of the perturbed case four tuples is subtracted from the nominal four tuple. For each perturbation variable, the difference with the largest absolute value is assigned to the error vector as the perturbation error.

$$e_r = \max\left\{\left(\phi_{D_{r,s_r}}, \lambda_{r,s_r}, a_{r,s_r}, b_{r,s_r}\right) - \left(\phi_{D_{nom}}, \lambda_{nom}, a_{nom}, b_{nom}\right)\right\}_{s_r=1}^{n_r}$$

Where:

a_{nom}	nominal semimajor axis length
a_{r,s_r}	semimajor axis length for the s[th] value of the r[th] perturbation variable
b_{nom}	nominal semiminor axis length
b_{r,s_r}	semiminor axis length for the s[th] value of the r[th] perturbation variable
e_r	variation in parameter values for the r[th] perturbation variable
$\phi_{D_{nom}}$	nominal footprint center geodetic latitude
$\phi_{D_{r,s_r}}$	footprint center geodetic latitude for the s[th] value of the r[th] perturbation variable
λ_{nom}	nominal footprint longitude
λ_{r,s_r}	footprint center longitude for the s[th] value of the r[th] perturbation variable.

The state covariance matrix, for the containment boundary center, is then computed as

$$C_s = e_{1,2}^T e_{1,2}.$$

Where

$e_{1,2}$ is the latitude and longitude columns of the error array.

The containment boundary semimajor and semiminor axis variances are computed as:

$$\sigma_a^2 = e_3^T e_3$$
$$\sigma_b^2 = e_4^T e_4$$

Where

e_3 is the semimajor axis column of the error array

e_4 is the semiminor axis column of the error array.

The χ^2 value is computed from the user specified containment probability by solving

$$\int_{\omega=\chi_0^2}^{\omega=\infty}\left[\frac{\omega^{\left(\frac{k}{2}-1\right)}}{2^{\frac{k}{2}}\Gamma\left(\frac{k}{2}\right)}\right]\exp\left(-\frac{\omega}{2}\right)d\omega = p$$

where

k number of degrees of freedom

p containment probability

for χ_0^2. The ellipse containing the footprint center motion is defined by

$$(\bar{y}-\bar{\mu})^T C_s^{-1}(\bar{y}-\bar{\mu}) = \chi_0^2.$$

Where

C_s^{-1} 2 by 2 covariance matrix for containment boundary center

$\bar{y}$ vector of containment boundary center variables $(\phi_D, \lambda)^T$

$\bar{\mu}$ vector of containment boundary center average values $\left(\phi_{D_{nom}}, \lambda_{nom}\right)^T$.

This produces and equation of the form

$$Ax^2 + Bxy + Cy^2 = \chi_0^2$$

where

A the element in the first row and first column of C_s^{-1}

B the element in the second row and first column of C_s^{-1}

C the element in the second row and second column of C_s^{-1}

χ_0^2 the Chi-square distribution value corresponding to the selected containment probability.

Rotating coordinates by the angle

$$\theta = \frac{1}{2}\tan^{-1}\left(\frac{B}{A-C}\right)$$

produces an equation of the form

$$A'x^2 + C'y^2 = \chi_0^2$$

where

A' equal to $A\cos^2\theta + B\sin\theta\cos\theta + C\sin^2\theta$

C' equal to $A\sin^2\theta - B\sin\theta\cos\theta + C\cos^2\theta$.

From this equation, the semimajor and semiminor axes of the containment boundary center motion are computed as:

$$a = \sqrt{\frac{\chi_0^2}{A'}}$$

$$b = \sqrt{\frac{\chi_0^2}{C'}}$$

The containment boundary semimajor and semiminor axis variance, corresponding to the specified containment probability, is computed as

$$\sigma_{total_a}^2 = \chi_0^2\sigma_a^2$$

$$\sigma_{total_b}^2 = \chi_0^2\sigma_b^2$$

The worst case containment boundary semimajor and semiminor axis lengths are defined as

$$a_{cb} = a + \sigma_{total_a}^2$$

$$b_{cb} = b + \sigma_{total_b}^2$$

The center of this containment boundary is $\bar{\mu}$, previously computed. If the containment boundary center motion latitude variance is larger than the longitude variance, the semimajor axis is rotated $\operatorname{sgn}(\theta)(90 + |\theta|)$ degrees from North. Otherwise, the semimajor axis is rotated θ degrees from North.

Implementation

Given the extremely short schedule and limited funding to generate a feasibility study, the ideal formulation of the covariance solution was not implemented. The first deviation was not a deviation in methodology. Only vehicle collision scenarios were considered. This is consistent with the highest priority safety analysis as indicated by WSMR range safety personnel for the THAAD program. Range safety has a good understanding of the safety consequences of destroying a booster in flight from previous experience. This first draft software did not provide the opportunity to change the characteristics of the colliding vehicles. For the purposes of the feasibility study, collisions were assumed to be between two vehicles, each of which possessed satellite characteristics. Satellite vehicles are dense. When they collide the tendency is to create large numbers of small fragments, with relatively few large fragments generated. For vehicles with this definition, there are no assumed intact components.

Winds are not included in the feasibility version of the analysis tool. At the time this tool was implemented, winds were not an option. Addition of winds is not difficult.

The containment boundary is assumed to only be at ground level. Addition of containment boundaries at other levels is straightforward. Such a containment boundary might be useful for evaluating aircraft hazards.

Only one debris cloud for each case is generated. This fails to limit the analysis to analysis variability. However, this is sufficiently accurate to demonstrate the computational steps. One danger, arising from this implementation, is the sense of speed of computation. While it is true that the covariance approach is significantly faster than the Monte Carlo approach, real world analyses will typically use additional debris cloud to mitigate analysis to analysis variability. Computation time required for the analysis is a approximately linear function of the number of debris clouds generated. An analysis using 10 debris clouds per case will take (approximately) 10 times longer to execute than an analysis with 1 debris cloud per case. Adding the capability to execute additional debris clouds per case is not difficult, but will require some software development.

The existing software does not compute the same error vectors or covariance matrix as the methodology in the previous section. This implementation was an approximation, made in a hurry, and needs to be upgraded. This modification should be relatively easy to implement.

Chi-square distribution values are determined by linear interpolation in a rather limited table of values. This should be upgraded. If the computation technique for Chi square distribution values is not upgraded, the interpolating table should be significantly enhanced. Enhancing the interpolation table should be tedious but easy. Implementation of an integral computation of the Chi square distribution value will be more difficult.

Methodological Limitations

Limitiations in the methodology arise from three primary (and necessary to simplification) assumptions: Gaussian random variables and processes, independence between perturbed variables, and linear relationships between variable perturbations and footprint consequences. The computation of the covariance matrices, the semimajor and semiminor axis variances is based on the assumption of independent Gaussian variables. Without the assumption of Gaussian variables, the process for computing the covariance matrices and the variances is invalid (assumes the sum of Gaussian variables is Gaussian). Without variable independence, the results are invalid (the consequences of variable dependencies are ignored). Gaussian variables and processes are assumed when the Chi square distribution is used to compute the containment boundary for a specified probability value.

Linearity of the footprint response to a variable perturbation is also a key assumption for the validity of the covariance matrices and variances. Taking the largest footprint dispersion for a variable perturbation set is an approximation which is conservative. There will perturbation regions for which the computed results are invalid, if the perturbation response is not linear. The user is best protected from this effect by using several perturbation values and examining the perturbation response curves.

In spite of these limitations, it is expected that this analysis tool is, and will be, useful. The underlying assumptions are not seriously violated for any parameter except wind. Wind is certainly independent of the other variables and is appropriately modeled as its own covariance matrix (which by independence, can be added to the covariance matrix for the other state variables). Targeting to day (or even time) of launch winds will produce a more statistically valid result.

The advantage of this technique remains its on-going operational flexibility. Once the analysis has been performed (and the underlying assumptions understood and accepted), the output covariance matrices and variances can be used (without further analysis) to compute additional containment boundaries for other desired containment probabilities. It is even possible to reverse this process and compute the containment probability for a boundary with specified semimajor and semiminor axes. This capability should prove extremely useful to mission planners and range safety personnel.

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